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LEGUMES IN AGRICULTURE

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R. O. Whyte
G. Nilsson-Leissner
and
H. C. Trumble

Plant Production Branch
Agriculture Division

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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PLATE I. Red clover (*Trifolium pratense*)

Photo by courtesy of the Division of Forage Crops and Diseases, U.S.D.A.

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SQUARCI-ROMA - VIA LABICANA, 92 - TEL. 71.006

Part I

CHAPTER ONE

ECONOMIC BOTANY OF LEGUMES

The two groups of plants of greatest importance to world agriculture belong to the plant orders, Gramineae (cereals and grasses) and Leguminosae (peas, beans and the grain, forage and green manure legumes). In this publication we review the present state of scientific and practical knowledge and experience on the latter group. This is not intended to be a textbook on legumes, but rather to indicate the problems which are at present engaging the attention of agronomists and others engaged on research in many parts of the world. Because we deal with current research and opinions, many of the chapters end, as it were, with a question mark indicating where knowledge is inadequate; this we hope may stimulate further investigation on one of the most potentially fruitful aspects of agricultural research and production.

The word " legume " is derived from the Latin *legere*, to gather, presumably because it was the custom to collect the seed pods of legumes by hand, rather than by a sickle as with grasses which do not shed their seeds so easily. The term " legume " has, possibly because of its French meaning, come to be employed also for a wide range of vegetables which are harvested by hand, and used for cooking, but in this publication, as in agriculture generally, the term refers only to members of the Leguminosae.

Legumes have been grown as crops for at least 6,000 years. The lake dwellers in Switzerland, 5,000 to 4,000 B. C., apparently cultivated a few plants, including peas, and a dwarf field bean was added during the Bronze Age. Chinese literature records the cultivation of the soyabean between 3,000 and 2,000 B. C. Legumes featured in the cropping systems of the early Egyptian dynasties, and later in the Roman era several writers stressed their value for food and soil improvement. American Indians have from the earli-

est times raised beans among their maize; beans also form an important part of the indigenous diet in Latin America. Although the value of legumes has long been recognized, their method of functioning through root nodule bacteria remained unknown until revealed by scientific investigations made less than 75 years ago, late in the 19th century.

Conclusive evidence has shown that legumes differ from other food plants in having the property of obtaining, through symbiotic root nodule bacteria, combined nitrogen as an available nutrient from the inexhaustible supplies of inert nitrogen in the atmosphere. This renders them independent of nitrogenous manures and makes them analogous to a nitrogen factory on the farm. Such a factory tends to remain active during the growth of the host plant; after growth has ceased, the nitrogen already fixed may still retain a substantial value. The legume may be ploughed under, eaten by grazing animals, or harvested; the nitrogen gained from the atmosphere finds its way partly into animal and human protein and, in a large measure, into the soil as an agent of enrichment, provided the excreta of animals feeding on legumes or legume/grass mixtures are voided on or transported to the soil. As a rule, half to two-thirds of the nitrogen fixed by herbage legumes is gained by the soil when these legumes are grazed *in situ*.

Morphology

Legumes are characterized by several important morphological features. The seeds are always enclosed in a characteristic pod. The leaves tend to be dark green and are usually divided into leaflets. The roots bear nodules containing specific bacteria which play a unique and vital role in the nutrition of these plants. The flowers of legumes vary greatly in size and attractiveness. In the sub-family Faboideae, to which belong the beans, peas, vetches, clovers, lucernes, and most of the other common legumes, the flowers have the well-known butterfly shape. In the Caesalpinioideae, the flowers are also irregular and appear in comparatively loose racemes or clusters. In the Mimosoideae, the third sub-family, the regular flowers are usually collected in dense heads. In the " butterfly " flowers, an upper large petal or "standard" is folded over the remaining four petals in the bud; the two smaller petals at the sides are the " wings; " and the two remaining petals, also smaller, are firmly pressed together beneath the flower to form the " keel ". Usually the keel-forming petals are actually united; they enclose the ten stamens, which may form a tubular sheath surrounding the pistil. Because the staminal sheath encloses the pistil, and the keel encloses both stamens and pistil, it is usually necessary for

the keel to be " sprung " or " tripped "; insects are, therefore, important agents in pollination. The flowering heads of lucerne and most clovers are composed of numerous small flowers constructed in this way. Many leguminous shrubs and trees often produce irregular and sometimes incomplete flowers; but they are essentially similar in construction.

The seed pod is characteristic of the family. It develops after fertilization of the ovule or ovules within the single pistil, usually but not invariably with pollen brought by an insect from another plant. The mature seed pod of most legumes contains several seeds, but there may be only one, as in some true clovers. Frequently, the pod is straight and long as compared with its breadth, but it may be jointed or constricted between the seeds. In lucerne and other species of *Medicago*, the pod is spirally wound and thus appears coiled.

The leaves of the true clovers are compound, divided into three leaflets (trifoliolate) almost always with short stalklets of equal length. The species of *Medicago* and the sweet clovers (*Melilotus*) also have trifoliolate leaves, but the central leaflet is borne on a longer stalklet than the lateral ones. Most other legumes have leaves with more than three leaflets; there is usually one terminal leaflet or tendril and the remainder are arranged in opposite pairs on both sides of the leaf stalk. Sometimes also the side leaflets are divided into pairs of smaller sub-leaflets. In a few leafless shrubs and small trees, the functions of the leaves are assumed by the stems, portions of which may be modified to resemble leaves. Legumes frequently have a central tap-root which carries numerous fine branches.

Germination and symbiosis

Two types of germination are characteristic of the legume family: (1) epigeal, in which the cotyledons, usually enclosed within the seed coat, are pushed above the soil surface by the rapid elongation and straightening of the hypocotyl, and (2) hypogeal, in which the hypocotyl elongation is limited, the cotyledons remain in position within the seed coat in the soil, and the epicotyl, more fully differentiated prior to germination, pushes up through the soil. R. R. Gates (1951) finds that the Mimosoideae and Caesalpinioideae are apparently all epigeal, whereas in the Faboideae (Papilionatae) some tribes are epigeal, some hypogeal; both types of germination are found within the Trifolieae and Phaseoleae.

At an early stage, frequently within a few weeks after germination, bacteria of the genus *Rhizobium* enter and infect the root through the root hairs. These " nodule " bacteria are carried

considerable distances in dust, or freely through the air, or on the surface of seeds, or in water passing through the soil. Infection of the root can take place within a few hours and only a relatively few points of infection may be necessary. The presence of the bacteria stimulates the rapid growth of adjoining root tissue, resulting in the formation of the nodules which soon become visible to the naked eye.

The rhizobia or nodule bacteria derive their energy from the host plant, which in return receives nitrogen which has been " fixed " or rendered available by the bacteria; this can meet the needs of legumes when soil nitrogen is limited. In such a mutually beneficial association or " symbiosis, " nitrogen fixation is achieved by the bacteria through the chemical combination of nitrogen with hydrogen to form amino-acids and ultimately plant protein. High protein content and independence of soil nitrogen resources – provided the plants are effectively nodulated and supplied with nutrients other than nitrogen – account in large measure for the vital importance of legumes in agriculture.

Relation to environment

Legumes suitable for one purpose or another may be found wherever agricultural settlement has developed but the degree to which they are utilized in the more primitive communities depends more upon social and economic factors than on natural circumstances and availability of plant material. Each species has strains adapted to a particular range of climatic and soil factors, among which temperature, duration of daylight, moisture and aeration of the soil, degree of acidity or alkalinity, and the availability of specific soil nutrients are especially important. Certain legumes, such as white clover, red clover and subterranean clover (*Trifolium repens*, *T. pratense* and *T. subterraneum*), are confined to regions characterized by moderate temperatures during the period of active growth. Others, such as lucerne (*Medicago sativa*), can withstand high atmospheric temperatures provided the relative humidity of the atmosphere is low and the soil does not become waterlogged at high temperatures. Species of *Desmodium*, *Stylosanthes*, *Indigofera*, *Centrosema*, *Calopogonium* and *Pueraria* are adapted to tropical conditions and are found mainly where high atmospheric temperatures are associated with high relative humidities. While many legumes, including lucerne, require well drained soils, others such as strawberry clover (*Trifolium fragiferum*) and some of the birdsfoot trefoils (*Lotus* spp.) can withstand periods of inundation.

Legumes are sensitive to climatic changes because active nitrogen fixation is dependent on the rate of carbon assimilation, which

in turn is governed by temperature and the duration and intensity of light. Moreover, the mesophytic character of the leaves of most legumes and the large amount of transpiring leaf surface exposed to atmospheric influences suggest a greater reaction to changes in atmospheric humidity and a higher rate of water loss by transpiration than occurs in most grasses.

Standard world classifications of climate give some indication of the global variations of average conditions of temperature and rainfall, but the nutrition, growth and development of legumes are to some extent dependent upon factors which do not feature in these standard classifications. Moreover, the average conditions on which the latter are based fail to take into account seasonal variations and the incidence of seasons which may or may not be favourable for particular legumes.

The important environmental factors are air temperature, duration and intensity of sunlight, amount of precipitation, its distribution over the periods when temperature and light are favourable, and its effectiveness, which depends upon the capacity of the soil to hold water within the root zone of the legume and the evaporation from soil or foliage after rain. Soil temperatures are also important, but tend to lag behind changes in air temperatures. Over most of the earth's surface the growing season for legumes is confined, as with other plants, to a portion of the year only. This is determined, in the first instance, by latitude; as the distance from the equator becomes greater, the period of the year in which growth is possible becomes restricted to fewer months owing to the low temperatures and reduced conditions of light prevailing at the higher latitudes. A small number of months, however, provide extremely long days in summer at these latitudes. This increasing period of sunlight per day between the spring and autumn equinoxes ensures a longer exposure in terms of total light hours than is at first apparent from consideration of the relatively short total period over which growth is possible. Towards the equator, the period of active growth may be restricted to a portion of the year only, when rains are effective.

At low elevations in the tropics, growth is not inhibited by low temperatures or short days in any month; there are in this region limited areas where soil conditions are favourable and moisture is available to roots more or less continuously, but here agriculture is probably already intensive and legumes are rarely grown in competition with more lucrative crops. As elevation increases in the tropics, the mean annual temperature falls by approximately 1° F. every 300 feet (1° C. for each 165 metres) and snow is reached in the Andean region of South America at about 15,000 feet. The prevailing temperature, therefore, ranges from about 80° F. (28° C.) at sea level, to freezing point at 15,000 feet and this will tend to remain

comparatively uniform, apart from diurnal fluctuations, throughout the year. At any elevation below the snow line, the period when adapted legumes will grow largely depends on seasonal availability of moisture.

The time of year when growth commences depends on coincidence of temperatures favouring seed germination or sprouting and availability of soil moisture. If moisture continues to be available, growth will proceed according to the range of temperature and light conditions which prevail. The time of flowering and seed

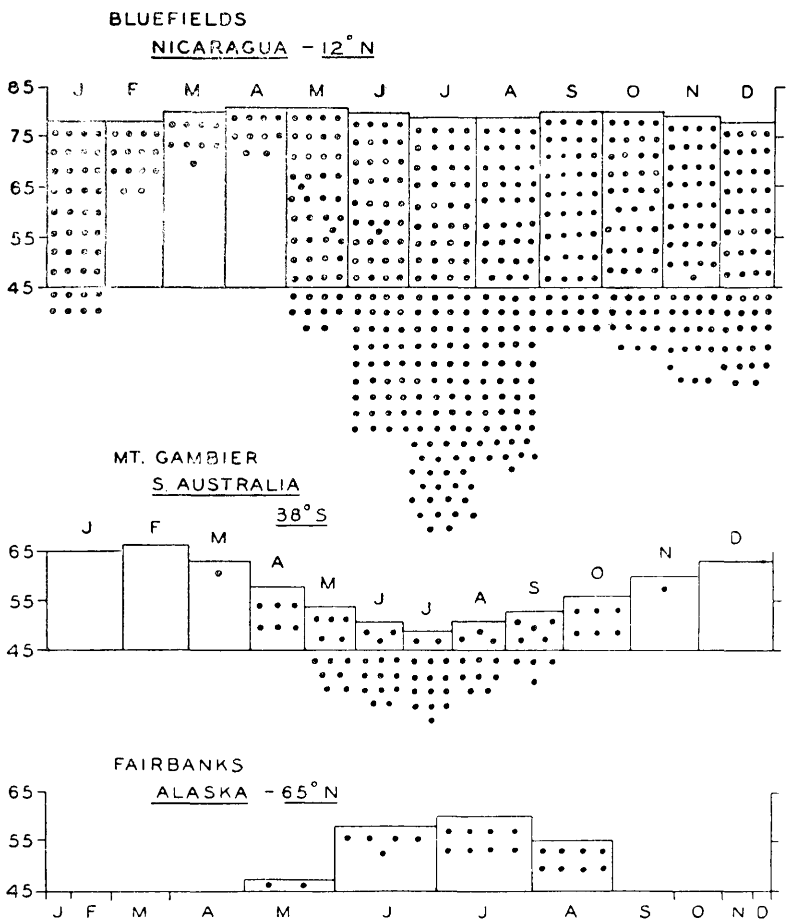


FIG. 1. Climatic patterns as indices of nutrient requirements. The above diagrams show the average conditions of temperature, light duration and moisture supply in widely separate and divergent centres. The adaptation of legumes to particular regions depends on the climatic features of the environment as here illustrated.

formation is governed by both temperature and duration of light; even within the tropics, time of flowering may be affected by changes in day length in either direction of as little as half-an-hour.

Prevailing conditions of climate can be illustrated by patterns, as shown in Fig. 1, which are based on a monthly representation of mean air temperature, average duration of daylight, and amount of moisture available for each successive month. The diagrams give an integrated picture of the three most important climatic variables, and show average conditions at three centres widely separated in latitude. To provide a picture of conditions as they occur over a representative period of seasons, patterns should be constructed for each year and the frequency of occurrence of particular types assessed.

There have been few investigations on the influence of specific climatic factors upon the nutrition, nitrogen fixation and production of legumes, but it is known that temperature and light govern carbon assimilation and so affect carbohydrate content, subsequent absorption of mineral nutrients from the soil, and fixation of atmospheric nitrogen. Phosphate, zinc and copper are absorbed in relation to climatic changes, and the range of variation in climate from season to season in a given region will determine the species and strains of legumes which may be grown. A detailed knowledge of the climatic features of a region is of value in indicating other parts of the world from which new legumes may be introduced.

Soil

Marked variations in soil type and fertility may occur within one climatic pattern. Sometimes soil changes accompany climatic changes and are in part dependent upon them. The factors of particular importance to legumes are the physical capacity of the soil to hold and to release water and oxygen to the plant, the acidity or alkalinity of the soil as shown by its pH value, its content of necessary nutrients, and the absence of undesirable substances such as soluble salts or organic products which may prove toxic to the legume or to the rhizobium on absorption. Sometimes drainage is necessary to provide aeration and to remove soluble substances such as excess salt. Provided the soil contains and permits a ready flow of both water and air and is free from detrimental concentrations of soluble material, the factors of importance are the pH value and the availability of essential nutrients.

Soil reaction appears to govern the distribution of certain legumes and is often confused with the nutrient supply of available calcium, the application of which increases alkalinity or, alterna-

tively expressed, reduces acidity. But other substances such as sodium and magnesium increase soil alkalinity, at the same time adversely affecting the physical condition of the soil. "Acidity" and "sourness" of a soil are terms which are often confused. A soil may be acid and yet highly fertile for legumes such as subterranean clover, alsike and white clover; a soil may be termed "sour" merely because it is unproductive through poor drainage or soil deficiency. Liming does not necessarily "sweeten" the soil; it may improve drainage and facilitate the release of certain nutrients in an available form. Unproductive soils should be competently examined to determine what nutrients are deficient and these should be applied experimentally in the first instance when legumes adapted to the soil and climate are being sown.

The apparent need for lime of legumes, such as lucerne, sweet clover, birdsfoot trefoil and the medicks, has sometimes led to an erroneous emphasis on soil alkalinity. Provided that sufficient calcium is available as a nutrient, the other essential nutrients are not deficient, and the soil is in good physical condition, the degree of acidity or alkalinity may not be of great significance within reasonable limits. Lucerne can grow well in a particular well-aerated, friable soil in South Australia which is abundantly supplied with water and has a pH of only 4 to 5, because of the high content of available calcium. On the other hand, it is true that species of *Medicago* and some of the true clovers are usually found on alkaline soils. Subterranean clover is definitely restricted to soils which are neutral or somewhat acid and tends to be replaced by species of *Medicago* at a pH above 7.0.

Apart from nitrogen, the nutrients required by legumes are phosphorus, potassium, calcium, magnesium, iron, sulphur, copper, zinc, manganese, boron and molybdenum. The emphasis on individual nutrients or groups of nutrients tends to change in different countries, e.g., phosphate is primarily needed to promote growth of white clover in Great Britain and New Zealand; rather greater emphasis is placed on potash than on phosphate for lucerne cultivation in the light lands of East Anglia; trace elements frequently determine the successful cultivation of subterranean clover and other legumes in southern Australia. All nutrients are vitally necessary, some in greater quantities than others, and an excess of any one may be toxic. The last five trace or minor elements are necessary in extremely small quantities. Molybdenum is required at rates of 20 to 50 gm. per hectare, especially for the actual process of nitrogen fixation. Sulphur governs the subsequent use of nitrogen by the plant; it is required in the elaboration of sulphoproteins. Manganese, copper and zinc tend to become more available with increasing acidity, and molybdenum more available with increasing alkalinity.

Superphosphate has been used extensively for some time as a fertilizer on legumes, but until quite recently its effect had been attributed to its phosphorus content alone. In Australia, in particular, the calcium and sulphur contents of this fertilizer have great significance; a widespread deficiency of the latter element in Australian soils is being recognized.

The importance of the trace elements in the establishment of legumes has been proved in Australia. The workers at Sholapur, Bombay State (J. K. Basu and his associates), have produced 100 per cent. increases in yields of certain crops on the semi-arid Deccan by applying small doses of manganese and boron; zinc is also important. In the United States, boron deficiency causes "yellows" in lucerne.

Most soils which require legumes for soil improvement are either naturally low in available nitrogen, or have become depleted of this element through persistent cropping. In many cases of nitrogen poverty, other nutrients may also be lacking. The testing of new herbage or other legumes should, therefore, invariably be accompanied by effective seed inoculation, and suspected soil deficiencies should be investigated and corrected. It is essential to ensure a balanced and adequate supply of all nutrients in the soil if the legume is to play its primary roles of (*a*) providing a diet rich in protein, calcium and phosphorus for humans and domestic livestock, and (*b*) raising the fertility, and especially the organic matter status and nitrogen content, of soils which are either initially low in fertility, or which have become exhausted by overcropping, overgrazing and erosion.

Nutrient uptake as affected by light and temperature

Nodulation is poor in seasons characterized by short days or low light intensity. Similar effects are produced by shading, as in ungrazed or lightly grazed pastures. Both the infection of plants by nodule bacteria and the effectiveness of the nodulation in terms of nitrogen fixation improve usually as the supply of light increases.

The balance between the relative content of nitrogen and carbohydrate in the plant appears to be important within certain limits. Too much or too little carbohydrate in the legume may reduce nitrogen fixation; as the rate of carbon assimilation is thus a critical factor, the conditions of light and temperature on which it depends determine the growth and nitrogen content of the legume.

The nutrition of legumes is closely related to climatic changes, which affect the growth rate and modify the symptoms arising from deficiencies in nutrients such as phosphate, sulphur, boron and zinc. Temperatures of both air and soil are decisive. Changes

in permeability, induced by changes in soil temperature, influence the respiration of roots and the uptake of soil nutrients. Herbage legumes may be expected to yield between two and three times more for each rise in temperature of 18° F. (10° C.). The temperature ranges within which legumes grow most actively vary according to species, strain, and stage of growth. There are compensatory effects between light intensity, light duration and temperature. Changes in soil moisture also govern the composition of the plant and so its resistance to frost or drought.

The amount of zinc absorbed by subterranean clover in South Australia is increased by rising air rather than soil temperatures. Total uptake is also influenced by the length of the daily light period, which further affects the distribution of zinc in the plant. The effects of temperature and light are probably not independent. Increase of the zinc content of the plant by application to the soil, or by increasing the temperature or the duration of light, improves the yield at least in part by increasing the rate of carbon assimilation. Similar effects may apparently be obtained with phosphate, copper and other trace elements. Each species or strain is adapted to an optimal range of values of light and temperature throughout its growth, and the optima change according to the stage of development. Deficiency symptoms in subterranean clover, which grows in winter and spring, are most evident when light and temperature are at their lowest values; the symptoms in red clover, which grows in summer, become intensified when the values for light and temperature increase. The reason in each case is a shift of the climatic conditions towards or beyond the limits of the optimal range, which cannot be tolerated by the plant without detriment where the available supply of a particular nutrient or group of nutrients tends to become limiting. These considerations govern the choice of legume to be grown, date of seeding, grazing management and fertilizer treatment.

Cultivation and utilization of tropical and sub-tropical legumes

When one considers, from a global point of view, the evidence concerning the effect of legumes on soil fertility and on the yields of subsequent crops, the picture is extremely complicated. Much is already known about the place of legumes as the fertility-restoring break in cropping systems in temperate lands, and the relation between the method of utilizing the top growth and the degree and type of after-effect obtained. These questions are discussed in Chapters 3 and 4.

It is when one comes to consider semi-arid lands and most parts of the tropics and sub-tropics that conclusions are more difficult. In the first place, there are the economic and social factors. Subsistence farmers with restricted acreages cannot afford to release much land for the cultivation of a green manure crop which does not give any food or economic return. When ample land is available, peasant farmers prefer to practise shifting cultivation rather than to adopt a stable farming system based on what are generally assumed to be desirable rotations of legumes and other crops.

In addition to the direct economic return they provide in the form of grain, seed or green matter for human and animal consumption, legumes are of economic value in influencing soil fertility by improving the nitrogen and organic matter status of the soil, and by bringing up minerals through their root systems from the lower soil horizons. But one very important attribute in tropical and sub-tropical countries is the provision of protection for the soil against the sun and the rain. The primary object of agronomists and plantation managers must be to keep the ground covered and protected for a maximum period of the year. In studying the ability of legumes to meet this need, some type of classification in relation to growth form and habits is desirable, on the lines of that proposed by L. R. N. Strange (*see* p. 129). Once this need for protection is met, workers in temperate countries would expect tropical legumes to play their usual role of influencing soil fertility in one or more of the ways outlined above.

Workers in the Belgian Congo and elsewhere find that bush fallow, grass fallow or *Pennisetum purpureum* have as good an effect on soil fertility as legumes, or even better. One can only speculate on the reasons for this result obtained under certain combinations of tropical conditions. In heavily leached soils, leguminous roots may not be able to perform their normal function of reaching down to considerable depths in the soil and bringing up minerals to enrich the top soil. Legumes in heavy rainfall areas do not require extensive and deep root systems for the purpose of gaining moisture from the sub-soil, but a consequent limitation of the roots to superficial layers may drastically accentuate the effects of nutrient deficiencies in the surface soil. The shrubs and small trees of the bush fallow probably do reach below the leached soil horizons, and so the burning of their top growth prior to a new cropping sequence will provide a top-dressing of mineral-rich material on the soil. This may explain the good results obtained with a deep-rooted leguminous shrub like *Leucaena glauca*.

Grass fallow or planted perennial grasses may be superior to legumes for another reason. Even supposing that a tropical legume crop has a higher nitrogen content than a tropical grass, the total amount may be less; further, the leguminous organic material may decompose much faster than the gramineous, and may all have disappeared by the time the next crop is growing and ready to utilize

it. But any after-effect must in this case surely be associated with organic matter content possibly along with soil structure (cf. the classic work on elephant grass and soil structure in Uganda), and not with the mineral improvement referred to in the preceding paragraph.

The Second Meeting of the Working Party on Fertilizers of the F. A. O. International Rice Commission at Bandoeng in Indonesia, 5-10 May, 1952, received a report on the responses of different soil types to bulky manures, such as green manures, composts and cattle manure. Correlation of responses from organic materials on different soil types does not seem feasible at present because data on the soil types are insufficient. It appears that the effect of a particular manure on the paddy yield is related to the soil-climate complex; that is, both the soil type and climatic conditions of a region influence the response to a particular manure.

The Meeting agreed that the importance of green manures for increasing rice yields could not be over-emphasized. Much evidence from Indonesia and India suggested that green manures are more effective for paddy fields than ammonium sulphate on the basis of equal nitrogen. This was variously attributed to the other nutrients contained in the green manure, and to the increased reducing capacity in water-logged paddy soils with additional decomposing organic matter present, causing an increased rate of release of phosphate from ferric combination.

In view of the importance of additional nitrogen in improving the yield of rice, and the difficulties of increasing greatly the supply of nitrogen from inorganic sources, or from livestock and by-product processes, the Meeting felt that reliance must be placed on green manures. The two serious difficulties are seed supplies and damage to leguminous crops by straying livestock. It is difficult to give a farmer a return on a seed crop of a green manure legume to compare with that obtained from paddy or other cash crops. In India, the use of the unpalatable *Sesbania aculeata* is of value in reducing damage by livestock.

Another report to the Bandoeng Meeting concerned a comparison between legumes and non-legumes as green manures. *Crotalaria usaramoensis* was compared with *Eupatorium pallescens* and *Tithonia diversifolia*, both shrubs adapted to poor soils. At 25 tons per hectare on paddy fields, all gave good responses and were similar in their behaviour. The nitrogen content of the non-legume, *Eupatorium*, was higher than that of *Crotalaria*. It is obvious that all available plant material, leguminous and non-leguminous, can give striking yield increases in paddy under suitable conditions. Applications of 200 to 300 quintals per hectare of *Crotalaria* gave yield increases

of more than 20 quintals of dry paddy per hectare, or about 80 per cent. While it may be difficult in some cases to turn under heavy green manure crops, this may be done by dragging a log across the field and ploughing in the same direction, as practised on flooded fields in Taiwan. In some cases (Indonesia) only half the yield response was obtained when the material was *not* incorporated into the soil; in Malaya the reverse is true.

The use of the legume as the key plant in that form of alternate husbandry which has come to be known as "ley-farming" must be regarded as being confined to those countries with a long growing season. A temperate climate with ample and well-distributed natural rainfall or water for irrigation is required. It is doubtful whether countries which cannot reproduce these conditions can operate "ley-farming" to the full, entailing as it does the complete fertility cycle of soil/crop/animal/soil in a period of pasture years with periodic breaks for the cultivation of cereals and other cash crops. Countries not in this favoured situation are interested in other forms of alternate husbandry and in discovering how they may derive benefits from cultivating legumes which are to be used for some purpose other than grazing *in situ*.

Throughout this publication we have, wherever possible, given emphasis to the techniques and problems of tropical and sub-tropical regions. The chapter containing a précis of the replies to the questionnaire issued by F.A.O in August/September 1951 is the largest in Part I, and a great many of the legumes described in Part II are tropical or sub-tropical in origin and adaptation. Elsewhere in the publication we have drawn upon information as was available on such aspects as the place of legumes in natural associations and in crop rotation sequences and the special methods which may have to be evolved in growing legumes for animal grazing and feed in the tropics.

Apart from the 1936 publication of the former International Institute of Agriculture, Rome, entitled *Use of Leguminous Plants in Tropical Countries as Green Manure, as Cover and as Shade* – pp. 262, no comprehensive review of tropical legumes has yet been attempted. This is done here against a background of information and practices which have been developed in other regions. Now that it is completed, it is possible to see how little is known about legumes in the tropics and sub-tropics. Again, the chief limiting factors appear to be social and economic rather than a lack of leguminous species for all purposes apart from intensive grazing as understood in the white clover zones of the world. Within the existing genera and species, there is almost certainly great scope for the selection and breeding of improved strains adapted to different climates, soils and types of utilization.

Ecological and biotic relationships of legumes in associations

With the increasing demand for information on the environmental relationships and requirements and the reaction to defoliation by grazing and cutting on the part of leguminous species, there is a need for some type of considered ecological statement which can be used as a basis for evolving agronomic techniques and systems of management of grassland and natural vegetation generally. One still feels loath to attempt any such statement in relation to the facts set out in Chapter 2, but it is on data of this kind that the statement must ultimately be based.

The humid temperate lands are fortunate in having a few legumes such as *Trifolium repens* which are stimulated by grazing in association with the maintenance of an appropriate nutrient and lime status in the soil. Then there are the leguminous species which occur in small percentages mostly in rangeland or in tropical and sub-tropical plant associations and which are eradicated rather than stimulated by anything except very light grazing. There is no indication yet of the discovery of a white clover for the tropics; the trend may be rather towards the cultivation of arable legumes in separate plots alongside natural grassland areas or cultivated grass crop, to be grazed, or more probably mixed, for feeding after harvesting. There is still a third group of leguminous species which come in when grassland climaxes or certain other types of associations have been subject to excessive grazing or burning. They are generally unpalatable, adapted to dry and sometimes alkaline conditions, and are liable to become noxious weeds over considerable areas. In this group one may perhaps place the associations containing *Cytisus* spp. studied in the Mediterranean environment of the South of France by the workers at Montpellier, together with species of *Acacia*, *Prosopis juliflora* and *Cassia tora* which represent a degenerate phase in succession from grassland or other vegetation type in semi-arid areas in other parts of the world.

The sowing of legumes in association with gramineous and other species is also based on ecological principles, in relation primarily to adaptation to environment, type and degree of utilization, compatibility between species, competition and similar factors. But the great problem in the improvement of grassland and fodder production from legumes, and in the greater use of legumes as green manure or cover crops, is the shortage of seed. It is one of the common complaints throughout those tropical and sub-tropical countries which show an awakening of interest in the cultivation of legumes. Associated with this is the need to extend plant introduction and exploration, so that a country may make full use of its own natural resources or those of other lands. In Chapters 10 and 11, we indicate

various stages in and methods of approach to plant introduction and the production of improved strains of herbage and other legumes for the same or new environments.

Legumes in systems of alternate husbandry

Research agronomists in areas at present practising exploitive forms of land use will be interested in the development of research techniques for the examination of various systems of alternate husbandry. They will also wish to study the correct combination of cultivated land on the one hand with uncultivated natural grazing land on the other, since it is being increasingly realized that this is in many cases the basis of correct land use.

Before rotations and systems of land use reach the pilot farm, the research worker has to study them on a small scale. In order to ensure the significance of the results, decisions as to appropriate plot lay-out, replication and technique must be arrived at in consultation with suitably qualified people. The choice of possible rotations and the alternative systems of land use and husbandry are generally so varied that it may not be possible, with the average facilities of a research station, to study more than one or two possibilities thoroughly at one time.

Research agronomists who wish to develop this line of approach may with advantage refer to the method adopted in South Africa by J. W. Rowland, and described by him in *Farming in South Africa* for April and May 1951.

This technique was evolved to study simultaneously: (*a*) rotation of crop and animal husbandry on arable land formerly devoted to maize monoculture; (*b*) management of natural veld adjacent to this cultivated land, and (*c*) the correct integration of the two.

The ley used in this rotation was not by any means the usual type as understood in humid temperate lands, as its composition and method of establishment had to be adapted to the environment and the species available. The objective of quick and cheap establishment was achieved by planting cowpeas in rows, and then planting grass in the rows when the cowpeas reached a height of 6 inches. If the cowpeas are planted on contour rows, the grass can then also form perennial barriers against soil movement. The grass rootstocks may be planted by mechanical planters; the grasses used were Napier and *Setaria* (Kazungula variety). Again we see the trend away from the mixed legume/grass associations of humid temperate lands to separate but contiguous cultivation.

The form of the veld and the ley depends to a great extent on the amount of veld or permanent grazing that is used in conjunction with the temporary leys on the ploughed land. Also, the ratio of veld to ley determines the ratio of crops to ley which would

be permissible in any particular soil type. To study this integration in the South African trials, varying proportions were taken with a 10-morgen* unit, for example, all veld, or veld/cultivated ley in ratios of 9 : 1, or 6 : 4, or 4 : 6. A full discussion of the results is out of place here, but they do apply directly to all cases where leys, including legumes, are to be introduced into farming systems. In addition to the great increases in fertility and forage yields which were obtained, an outstanding result for propaganda purposes is that the cash return from animal produce (in this case milk sales) compares favourably with the gross revenue which may be expected from annual cash crops in this area.

Discussion and experimentation might well centre around the words of J. W. Rowland quoted below, and the extent to which such a method of land husbandry can be applied in relation to the many combinations of climate, soils, and systems of farming and land tenure which exist throughout the world, with particular reference to tropical and sub-tropical conditions.

> "The heavy yields and obvious dependability of artificial pasture and the potentiality for large cash incomes from animal products raised on combinations of veld and pastures bring within sight the end of the exploitation period of South African agriculture. Instead of the ruin that can be caused to soil and vegetation by uncontrolled grazing by extensive herds and flocks, instead of the destruction caused by tractors and ploughs, and pulverising implements used for continuous clean-cultivated annual crops on unsuitable soils, husbandry based on sustained yields can come into being, and manure farming can start. Rich pastures can build fertility and bring substantial returns from the many subsidiary forms of livestock that can be linked with the milk cow. The turned sods can then safely be subjected to the severest pulverising and cultivation processes for the rapid production of heavy annual crops, and stable intensive farming on small units of land will be possible ".

The Pilot Farm

In areas of monocultivation or other forms of exploitive or unstable husbandry, the advisory and experimental officers of the Department of Agriculture may wish to demonstrate the value of a particular legume or legumes in improved farming systems. As few areas of any size are completely uniform, this is probably best done by strategically located pilot farms. These would be similar in size and lay-out to the neighbouring farms, and should if possible be operated by a farmer with guidance from the advisory service. Capital and other facilities should not be abnormally favourable; full accounts should be kept. Such farms were recommended for all Mediterranean countries by the Mediterranean Survey Group of the Organization for European Economic Co-operation (O.E.E.C.) (1951), and are already adopted in a number of European countries,

* 1 morgen = 2.12 acres.

including Portugal and the Netherlands. They would seem to be essential in all countries where a change to stable forms of alternate husbandry based on the use of legumes requires local trial and demonstration.

The South African Department of Agriculture already has six pilot farms in operation and several more are being planned. Technical officers of African Explosives and Industries Ltd. have one such farm. It is agreed that they are essential and that they impress farmers more than mere demonstration plots.

The Grasslands Division in New Zealand has used the pilot farm most successfully to demonstrate the value of bred strains and systems of intensive pasture management, both in fat lamb and dairy production. The one-acre farmlet divided into 1/10th acre fields is also a most valuable tool in studies on farm management. The same series of farmlets has been established at three widely separated localities where a comparison is being made between full utilization (all grass), hay and silage (all grass), special-purpose pasture (all grass) and a variety of rotations. Despite the fact that mature wethers are being used for grazing purposes, these farmlets have stimulated much interest among farmers, many of whom have applied the principles on their own dairy and fat lamb farms with outstanding success.

Chapter Two

ECOLOGICAL AND BIOTIC RELATIONSHIPS

Although it might well be a study which would yield results of great economic importance, no one has yet attempted to review the place of legumes in world phyto-geography, nor the ecological and biotic relationships of legumes with their associate species in natural or induced associations. Would it, for example, be correct to state that the great majority of legumes occur naturally or are important economically (without irrigation) in those parts of the world which were formerly or are still forest or savannah woodland? The greatest contribution of white and red clover, and possibly also lucerne, to the world's grazing resources has been in humid temperate forest climax zones.

In New Zealand, the pastoral industry has arisen on the 14 million acres of land which were largely virgin forest, and white clover is the key pasture legume. There are some 14 $^1/_2$ million acres of sown pasture in Australia which are mainly confined to cleared forest or savannah woodland and which, with the exception of the Rhodes grass pastures of Queensland, are based on the pasture legumes, subterranean clover, white clover and lucerne. In addition, there are vast unrecorded acreages of open semi-arid savannah, especially in New South Wales, where the annual medicks, *Medicago denticulata*, *M. laciniata* and *M. confinis* have become naturalised and make an important contribution to the stock diet, particularly of merino sheep.

We shall, in this chapter, present some of the information which has been available to us in publications or provided by correspondents, to indicate the little that appears to be known concerning the occurrence of legumes in certain types of natural or induced plant associations.

Legumes of various growth forms occur in most of the major vegetation zones of the world, although they are rare or frequently absent from the great areas where grassland of the type found in the steppes, the American range, the veld and the pampas is the ecological climax. There are many leguminous shrub and tree species in the forest and other associations, such as form a conspicuous feature of natural savannah in parts of Africa, India, the dry pastoral areas of southern Australia and especially in Central America, where Standley has recorded some 400 species of legumes, mostly shrubs and trees. Species of the genus *Acacia* are particularly widely distributed in world vegetation.

Many of these trees are either of no value for fodder or inaccessible to livestock, apart from loppings or the pods and seeds which drop to the ground. The litter from leguminous trees may, however, have an effect on soil improvement. In those areas in which the climatic conditions are critical and where the natural vegetation is under considerable pressure from the grazing and browsing livestock population, more information is needed on the proper utilization of the leaves, pods and even the bark of fodder trees and shrubs, of which so many belong to the Leguminosae. This is important for the improvement of the livestock industry and for raising the general level of animal nutrition in what have so far been nomadic systems in primarily pastoral areas. It is at the same time important to recognize that past and present misuse of grazing resources of this type has been the cause of great denudation of vegetation. Although current economic and social factors make it extremely difficult to visualize any great change in the present system of land use, the ultimate objective or ideal must surely be to bring the livestock industries and the type of animal husbandry more into equilibrium with the climate, the vegetation, and the soil which it should protect.

Tropical and sub-tropical vegetation zones

At least 75 per cent. of the trees and shrubs of Africa are either browsed to some extent by domestic or wild animals, or are cut or lopped for fodder. M. H. French, of the Tanganyika Department of Agriculture, states that fodder trees and shrubs are of greatest importance in areas of semi-desert shrub or similar vegetation communities, in which grass is scarce or practically non-existent, sometimes for the greater part of the year. Now these fodder plants, in contrast to grass, come into leaf early in the season and before the first rains, and retain their nutritive value at a moderately high level well into the next dry season.

So long as animals can obtain sufficient roughage from grass and crop residues, the leaves and pods of fodder trees are only of supplementary value, but once the grass has been eaten out or has become quite unpalatable, their green shoots and dead leaves may form the bulk of the ration. One authority states that the composition of leaves and pods shows seasonal changes somewhat similar to those occurring in grass, but that these changes are of a smaller order of magnitude, particularly for protein, minerals and fibre; another states that the composition of leaves and buds does not show seasonal changes similar to those characteristic of grasses. In any case, in seasons of drought, when grass is short and at its lowest ebb in protein and phosphorus, the foliage of trees continues to be well supplied with these nutrients. Trees and shrubs would

not be able to compete in yield of dry matter per acre per annum over a period of years with cultivated fodder crops where these can be grown, but for spasmodic lopping or other use in critical areas they do have considerable value. Whether this treatment must be accepted as part of a long-term land-use and conservation policy is open to question.

The *Flora of the Sudan*, by Broun and Massey (1929), lists 264 species of the Papilionaceae (Faboideae) and 47 species of Mimosaceae (Mimosoideae). According to M. H. Harrison, a large proportion of these "self-established" indigenous legumes are useful browsing or grazing plants, and a few are very important. Particularly in the dry season, animal owners place a much higher value on browsing than can be accounted for by the quantity of browse available compared with grass. Pods, leaves and flowers have a higher protein and mineral content than dry grass, and thus may possibly provide something required by the ruminal micro-organisms. The bulk of these browse plants in the Sudan are legumes, many of the more important ones being species of *Acacia*. But Harrison emphasizes that there is nothing special about legumes which makes them better browse than plants of other orders. The bush which has the best reputation as a browse plant throughout wide areas of cattle country in the Sudan is *Cadaba farinosa*, which belongs to the Capparidaceae. It just happens that the greater proportion of trees and bushes and of browse plants are legumes. As in other parts of the world, the importance of browse plants varies inversely with the rainfall. There are far fewer browse plants in high-rainfall country, and the grass there stays green for a larger part of the year.

Without browse plants, many areas of the Sudan would not be able to support the present numbers of camels and sheep; even in cattle country with its higher rainfall, browse plants are very important. During the dry season, the Beni Helba cattle, the best and largest cattle of Darfur, the Province from which comes 80 per cent. of the exported cattle of the Sudan, depend on the pods of *Acacia albida* as the chief item in their diet.

Some non-woody leguminous herbs are also important as grazing plants in the Sudan. In areas of Kordofan, particularly Messeria Humr country and in parts of Darfur, there are extensive areas of *Zornia diphylla;* this is excellent for cattle during the rains, if care is taken to avoid bloat. In Northern Province, when the floods recede from the basins covered by water at high Nile, there is a dense growth of the lucerne-like plant, keteih (*Trigonella laciniata*); this is an extremely valuable forage crop and is also important in building up soil fertility.

Only recently have ecologists and foresters in India begun to appreciate and understand the ecological composition and succession in their grasslands. It would appear that there are a number of different grassland types in India, varying from those in the dry

parts of the country in Rajasthan and the Deccan Plateau to the tall, rank-growing jungle grasses of the Tarai and Bhabar zones along the foothills of the Himalayas, and the plant communities in the cleared forest lands of the mountains themselves. All these associations are predominantly gramineous in composition. It has not yet been conclusively shown that any leguminous species of *Indigofera*, *Alysicarpus* or *Glycyrrhiza* can be established and more particularly maintained in Indian grasslands, under high intensity of grazing. Since grassland in India is sub-climax under forest of various types, this contradicts the thesis put forward at the beginning of this chapter concerning the frequency of legumes in forest climax zones.

The problems associated with the natural occurrence and cultivation of legumes in tropical and sub-tropical countries are discussed more fully in Chapter 7. It does appear that it will be very difficult to introduce a legume into tropical grasslands to play a role equivalent to that of *Trifolium repens* in humid temperate countries. It may be possible to establish pasture mixtures of tropical grasses and legumes on the Queensland pattern described on p. 98 or to grow legumes in wide-drill sowings, so as to permit control of weeds, or to grow several rows of annual tropical legumes between single rows of perennial grasses. The cultivation of legumes in tropical lands may not present great difficulties, but their establishment and maintenance in natural grazings is another problem.

There is no doubt that plant exploration in tropical and sub-tropical countries will ultimately yield fruitful results and we look forward with interest to the reports of the collection made by C. S. I. R. O., Australia in tropical and sub-tropical Africa in 1951/52. The discovery of perennial forms of *Arachis* in South America (p. 208) is an interesting example of new material becoming available.

Grassland climax zones

In those areas of the world where grassland of the steppe or related type is the ecological climax, one has to accept the perhaps unfortunate fact that the plant associations contain few if any legumes. With a few possible exceptions, it is improbable that man will be able to introduce or materially to increase legumes in these grass climax associations without ploughing up and cultivation. Although it might, on theoretical grounds, be supposed that a legume would improve the total yield and nutritive value of range herbage, little use can apparently yet be made of the principle in dealing with climax grassland. It is, therefore, fortunate that the grass species themselves frequently have a reasonably high nutritive value.

The other regions in which grass is the climax type of vegetation are the high alpine pastures above the tree line, such as occur in

Switzerland, Austria, and parts of Germany and France. These have a miscellaneous herbage of alpine plants, including clovers, which are generally stimulated by the operation of the grazing factor during the relatively short summer grazing period. The greater areas of alpine pastures in Central Europe are actually below the tree line in land which was formerly forest.

Much more requires to be known of the relationship between the type of grassland association and the possibility of stimulating the percentage occurrence and productivity of legumes therein. There seems little doubt as to the correct picture, discussed below, in the forest climax zones in humid temperate lands, such as Great Britain and Western Europe, the eastern parts of North America, and New Zealand. It is less clear in the Mediterranean environments of the world, and in certain so-called " natural grassland " areas of the United States, Australia and other countries. A fuller understanding of the ecology of these types of association is essential in assessing the possibility of growing legumes in them.

North American grasslands

For example, W. R. Chapline (1951) writes that the " natural grasslands " of the United States contain native legumes which vary greatly in value as forage plants for either domestic animals or wild life. A distinction has to be made between legumes which are desirable and undesirable in the natural vegetation, and it must be known how both these groups may decrease or increase under grazing by livestock. For example, in the Pacific North-west, continued overgrazing generally results in depleted meadows characterized by undesirable annual grasses and weeds. The appearance of perennial clovers is one of the first significant signs of better grazing management.

On millions of acres of former open grassland in the south-west of the United States, the desirable forage species have been replaced by the leguminous mesquite, *Prosopis juliflora*. Although ranchers once thought highly of mesquite pods and leaves as emergency forage, they now realize that the plant is very low in production of fodder and that it robs the soil of moisture, preventing maximum production of grasses and other good forage species. The increase of mesquite has doubtless been encouraged by overgrazing, and the dominance of woody species of this type has materially increased the cost of keeping livestock. Overshadowing these direct economic aspects is the greatly accelerated soil erosion which has occurred. The control of mesquite and its replacement by native or introduced forage species constitutes a major activity in the research work of the United States Forest Service in the south-west. This example has

an application in other semi-arid parts of the world, where too much notice is taken of the supposed fodder value of trees such as *Acacia arabica*, whereas the stimulation of the herbaceous ground cover would be a much more desirable objective.

The American range workers have found that proper range management, especially a moderate or reasonable degree of grazing, suitable seasonal use in relation to the growing season, and the deferring of grazing use until seed maturity of the perennial grasses, has helped to increase the plant cover and improve its composition. Such practices have also, in suitable areas, assisted in maintaining and increasing the abundance of choice herbaceous legumes such as the native clovers and vetches.

W. R. Chapline has provided the following list of the more important leguminous genera which occur as desirable constituents in greater or lesser degree in the native vegetation.

Table I. Important Leguminous Genera in the United States

Area		Common Name	Genus
Western States (Area west of 100th Meridian)	Great Plains and Prairies	1. Scurf pea	*Psoralea*
		2. Lupin	*Lupinus*
		3. Milk vetch	*Astragalus*
	Foothills	4. Pea vine (also 2 and 3 above)	*Lathyrus*
	Mountain (Meadows-open timber)	5. Vetch	*Vicia*
		6. Deer vetch	*Lotus*
		7. Clover (also 2 and 3 above)	*Trifolium*
	Great Valley of California	8. Bur-clover (an introduction now naturalized)	*Medicago hispida*
South-western States (Arizona, New Mexico and Texas)		9. Acacia	*Acacia*
		10. Mimosa (also 2, 3 and 4 above)	*Mimosa*
Southern States		11. Lespedeza (also 2 above)	*Lespedeza*

Most of these are desirable species which decrease in frequency with overgrazing. The pea vine and some species of lupin increase as the ranges deteriorate, particularly under cattle grazing, and become so abundant that the land has little grazing value. Unpalatable legumes such as *Thermopsis* are also indicators of overgrazing. These trends are, therefore, undesirable and are at the expense of more valuable grasses and other plants. On the other hand, when range lands are recovering from a very poor condition of many annual grasses and weeds of little value, the temporary increase

in the low value legumes for a few years until replaced by more valuable species may be highly desirable in increasing soil nitrogen, and is in fact an essential part of the ecological succession.

The response from the application of fertilizers to most arid and semi-arid range lands of the United States has been insufficient to justify the cost. The exceptions relate to grassland areas in what may be regarded as forest climax country. On some soils under the Californian annual type of vegetation, with winter and spring rainfall of about 16 to 20 inches (400 to 500 mm.) annually, the application of sulphur-carrying fertilizers has greatly increased the yields of clover. In the glade areas of the hills and mountains of the south-west and in Kentucky, West Virginia and Missouri, the use of lime and fertilizers combined with the planting of white clover, *Lespedeza* and other legumes, is economically desirable.

On forest ranges of the Southern Coastal Plain in the United States, the soils leach rapidly under a rainfall of 50 inches or more, and it is necessary to use fertilizers in order to reseed successfully. It has thus been possible to establish such legumes as Louisiana white Dutch clover *Lespedeza*, and *Lotus* and to improve the forage value of the range. A co-operative study is in progress in Southern Georgia on increasing the grazing value for cattle of cut-over long leaf pine areas by reseeding with *Lespedeza* and carpet grass (*Axonopus affinis*), or *Lotus* and Dallis grass (*Paspalum dilatatum*). Successful stands have been established. The second mixture requires more fertilizer but the production of forage and livestock is greater. Both reseeded areas are more productive than the natural wire-grass range.

Relative also to the south-eastern states, G. E. Ritchey says that in Florida it appears that by burning the forest range in July or early August and by seeding, satisfactory stands of domestic grasses and clovers can be obtained without ploughing and breaking the land.

Natural vegetation in South America

A similar trend from the arid and semi-arid grasslands, poor in palatable legumes, to the humid forest environments in which leguminous species can be stimulated by the application of soil nutrients and suitable grazing management can be seen in South America. A. Burkart (1951) has provided the following notes concerning species and successions which are not yet fully understood.

In dry central Argentina, especially in the shrubby Gobernación de la Pampa and in the Chaco, there are a number of leguminous

species, but they are infrequent, and grass is dominant in the steppe and savannah-type grazings. There is, however, an abundance of shrubby and arborescent sclerophilous species of Leguminosae, belonging to the sub-family Mimosoideae. Many species, particularly of *Prosopis* and *Acacia* (only *A. aroma* is of importance), have sweet pods which are of fodder value in the dry, hot season after the grass has disappeared. Many species of *Prosopis* are important, e. g. *P. alba*, *P. nigra*, *P. chilensis* (which gives the best pods), *P. alpataco* (grazed), *P. fero*, *P. caldenia* (the famous caldén of the Pampa, long recognized as an important forage tree) and *P. flexuosa*.

Cattle distribute the seeds of many of these trees, including undesirable types such as *Prosopis ruscifolia* in the dry Chaco, and *Acacia aroma*, when these spiny shrubs or trees grow very densely. Stockmen believe that these trees destroy the grasses. It is probably true to say that the grasses are eliminated by overgrazing and the leguminous trees occupy the denuded land because they are drought resistant. They may, of course, be stages in succession preliminary to the establishment of a forest climax. *Prosopis ruscifolia* grows even in low saline soils and may improve their condition sufficiently to permit the ultimate establishment of high quebracho forest (climax of *Schinopsis balansae* and *Sch. lorentzii*).

In Argentina and Uruguay, native and introduced legumes grow in sufficient quantity only in the better soils, with a minimum rainfall 24 to 32 inches (600 to 800 mm.) per annum. The grass steppe of Buenos Aires has herbaceous and nutritive legumes of the genera *Vicia* (*V. graminea* and relatives), *Lathyrus* (*L. crassipes* etc.), *Adesmia* (*A. bicolor* and relatives) and *Trifolium* (*T. polymorphum*). On cropped and heavily grazed land, these disappear and Mediterranean species become abundant, e. g. *Medicago hispida*, *M. arabica*, *M. minima*, *Melilotus indica*, all winter annuals, " strong " species more resistant to grazing than the native ones. During the hot dry summer there is a lack of legumes where lucerne is not grown.

The cultivated races of *Trifolium repens* have become widespread on the grazing lands of Buenos Aires by sowing or natural spreading. There is now a seed-producing centre in the region of Pergamino. *Lotus corniculatus* var. *tenuifolius* is increasing in importance in these lands.

To the north and east of Buenos Aires, soil fertility rather than drought becomes the controlling factor. In Uruguay and north-east Argentina (Entre Rios, Corrientes, Misiones), the lack of sufficient phosphorus, calcium and humus is very important. Lucerne, however, does not grow well without manure. The native legumes of the campos are of some importance, especially *Trifolium polymorphum*, *Adesmia bicolor* and *Vicia graminea*. G. Fischer in

Uruguay has found that clover and other wild legumes become strong and abundant in grass-dominant swards as a result of top-dressing with phosphates and lime. These natural legumes stand grazing well.

At Tucuman (6,000 to 7,500 feet) in the Andes, there are humid, temperate valleys where *Trifolium amabile* is important for the grazing of milk cows. In the humid Andes in Patagonia, *Vicia nigricans*, *Lathyrus magellanicus*, *L. hookeri* and herbaceous species of *Adesmia* are found, and *Trifolium pratense*, *T. hybridum* and locally *Lotus uliginosus* grow well under cultivation for forage.

The cultivation of legumes in the Argentine sub-tropics is, in general, limited by droughts. The humid areas, Misiones, the eastern Chaco along the Paraná-Paraguay, the western border of the Gran Chaco along the Cordillera from Bolivia to Tucuman, are suitable for the cultivation of *Vigna sinensis*, *Crotalaria*, *Pueraria thunbergiana*, *Stizolobium deeringianum*, *S. cinereum*, *Trifolium alexandrinum*, *T. incarnatum*, *Medicago sativa*, *Dolichos lablab*, *Glycine max*, *Phaseolus angularis*, *Ph. aureus*, *Centrosema pubescens*, *Arachis hypogaea*, and so on. The extension of cultivation is much hampered by lack of seed.

Humid temperate grasslands

From the regions of the world in which it is not yet clear whether the necessary ecological and biotic conditions exist to promote a high percentage of valuable grazing legumes in grazing lands, we turn to the humid temperate conditions. In the British Isles and Europe there occur the plant associations which have arisen or have been induced in areas formerly under various types of forest, and to which the names of pastures, meadows, grasslands or rough grazings have been given. It is in these associations that the herbage legumes, and particularly *Trifolium repens*, are usually present in amounts which permit them to make a contribution to grazing resources and soil improvement. By various agronomic means, these legumes may be increased in frequency to a point at which they can greatly influence the total yield of herbage and more particularly the protein content of the grasses with which they are associated.

In Germany, for example, E. Klapp states that one can reckon that 8 to 10 per cent. of the yield of *all* grassland areas is composed of legumes. On 65 to 75 per cent. of the area, the chief species are *Trifolium repens* (especially on pastures) and *Trifolium pratense* (especially in meadows). On 25 to 45 per cent. of the area, one finds

Lathyrus pratensis (only in meadows), *Lotus corniculatus*, *L. uliginosus*, *Trifolium dubium*, *Medicago lupulina* (meadows and pastures) and *Vicia cracca* (almost confined to meadows). The sowing of leguminous species is generally unnecessary as either there is enough viable seed available in the soil, or the seeds may be transported to the pasture by the grazing animal or in farmyard manure. There are, in Germany, no rough grazing lands in which at least traces of two or three legumes may not be found; even in the poorest and sourest *Nardus* pastures (pH = 3.5 to 4.5), one can find *Trifolium pratense* in 65 per cent. of the samples, *T. repens* in 57 per cent., and *Lotus corniculatus* in 48 per cent., together with 14 other leguminous species.

Some 80 species of the genus *Trifolium* are indigenous to the United States, but none has proved of any great agricultural value, apart from contributing something to grazing and the wild hay crop. The important developments in the improvement of humid temperate grasslands had to follow the introduction by the early settlers of *Trifolium pratense*, *T. repens*, and other clovers which had already become of value in the European countries from which they came. The same may be said of New Zealand for *T. repens*, and of Australia for this species and *T. subterraneum*, neither of which occurred in the original flora of these countries.

In the humid temperate conditions of the British Isles, wild white clover is the outstanding pasture legume. On fertile soils not too acid in reaction, it may be frequent, and may in association with grasses provide a herbage of high carrying capacity and nutritive value. As the *Grassland Survey of England and Wales* has shown, these companion grasses may be perennial ryegrass on the most fertile soils, and species of *Agrostis* and *Festuca* on the less fertile. In Germany, *Trifolium repens* occupies 17.8 per cent. of the area in *Lolium* pastures and 7.3 per cent. in *Agrostis/Festuca* pastures.

In spite of all the efforts directed in England towards the wider adoption of ley farming, and the great success which can be achieved from this system in experienced hands, there is no doubt that permanent grassland will continue to play an important role in the country's agricultural economy. A primary objective in the improvement of this permanent grassland will be an increase in the amount of white clover by proper grazing management following the application of phosphate and lime.

The work of W. E. J. Milton and R. O. Davies in the hills of West Wales may be quoted as an example (1947). An experiment was begun in April 1930 on hill farms at 850 to 900 feet above sea level, on two sward types, namely, *Festuca/Agrostis* and *Molinia*, and was continued until 1946. Data were collected on botanical composition of the enclosed plots, aggregate yields, yields of individual

species, seasonal yields, and annual analyses of the herbage on open and freely grazed plots. The data on yield and botanical composition have shown that the improvement has been progressive throughout the period of the trial. The establishment and growth of the volunteer lowland grasses and wild white clover have greatly increased the productivity and nutritive value of the herbage, but these species would not have succeeded but for the application of lime and/or fertilizers. Their success within a reasonable period was also dependent on the grazing animal. These species made a good contribution to pasture yields under grazing conditions six years from the commencement of the experiment; when hay and aftermath cuts were taken, however, the herbage remained in its original type until the 14th year, and then changed only at one of the two hay centres. Comparable German results refer to the treatment of *Nardus* pastures over a period of six years. With application of phosphate and lime followed by cutting only, there was no *Trifolium repens*. With phosphate and lime followed by fenced grazing, there was 13 to 18 per cent. *T. repens*, *T. pratense* and *T. dubium*.

From a purely practical point of view, therefore, the improvement of these hill swards, using the original vegetation as a basis, and adopting grazing or cutting and the use of lime and fertilizers, has shown that great benefit can be obtained from the indigenous herbage alone, but that the presence of the better grasses and wild white clover greatly enhances the improvement. The appearance and spread of these plants was quite an unexpected factor, but under practical conditions this phase could be hastened by the deliberate sowing of their seeds on the surface of the hill swards. The treading of the sheep with the addition of tooth harrowing where possible would bring the seeds into contact with the soil and ensure their establishment. Of all the aspects of this experiment, however, that of controlling the sheep grazing within fenced areas has had the greatest influence, for besides the importance of a concentration of animal manure and of treading, it has ensured complete and regular defoliation of the herbage. The produce of grazed plots yielded double the crude protein obtainable from plots subjected to hay treatment, probably because of the presence of the white clover itself, and also because of its effect on the yield and protein content of the associate grass species.

E. Klapp states that sowing of legumes is not generally necessary. There are many more meadows than pastures in Germany, and the hay usually contains ripe seeds of legumes. The seeds are then distributed with the farmyard manure or the undigested seeds are dropped by the grazing animals. On meadows and pastures which have become partially bare, surface sowing of legumes may be successful, but the quickest and most reliable method of stimulating them is by dressing with lime, phosphate and potash followed by controlled intensive grazing.

In New Zealand, by combination of closer subdivision permitting of better grazing management, oversowing with clover and top-dressing with phosphate, a steep hill country area on the west coast of the North Island has increased in carrying capacity from 1.5 ewes (plus cattle) per acre to 4.1 ewes with fewer cattle over a period of five years. J. Melville has stated that a similar improvement could be effected over at least 5 million acres in the North Island.

In the United States of America, pasture renovation has proved to be the most effective means so far developed for improving unproductive permanent pastures in humid regions, particularly on rough, rolling land. Renovation is a means of rapid and direct conversion from unimproved to improved pastures without growing an intervening cultivated crop. This method of pasture improvement involves: (1) thorough tillage by discs or spring-tooth harrows in order to subdue existing vegetation and provide a firm, well-prepared seed-bed, (2) adequate fertilization and liming, and (3) seeding with adapted high-producing grasses and legumes. As much as five-fold increases in production have resulted from pasture renovation in this way.

The next stage in the improvement of poor quality permanent pastures is the direct reseeding strongly recommended in Great Britain during the war years, particularly in hilly regions in the west. In many cases it was the usual practice to grow a pioneer grazing crop of rape and turnips followed by a cereal, in order to create the correct environment of good tilth, soil reaction and fertility for the establishment of high-fertility-demanding species of grasses and clovers.

Other forest climax areas with somewhat more severe climatic conditions in the form of long summer droughts are to be found in the Mediterranean lands, where there is an abundance of annual leguminous species belonging chiefly to the genera *Trifolium*, *Medicago*, *Vicia* and *Lathyrus*. These occur in favoured localities on the deforested mountain slopes, and are more generally abundant in the small, moist areas of natural pasture which occur near lowland villages in Greece, for example. Annual legumes are also frequent in the Anatolian steppe country, where it is believed the vegetation was formerly deciduous oak; here, species of the same genera occur in association with perennial grasses, *Artemisia herba-alba* and various rhizomatous and other types of lucerne.

(*a*) Before development

(*b*) After clearing and sowing subterranean clover but without phosphate

(*c*) Growth of subterranean clover 7 months after sowing, with 2 cwt. superphosphate per acre.

PLATE 2. (*a*) (*b*) and (*c*). Establishment of pasture on naturally poor land with good rainfall in Southern Australia

(Photos by courtesy of the Waite Agricultural Research Institute, Adelaide, Australia)

PLATE 3.

(*a*) The pasture shown in Plate 2 (*b*) after three seasons' growth

(*b*) The pasture shown in Plate 2 (*c*) at commencement of third season; the perennial grass, visible as nitrogen-deficient seedlings in Plate 2 (*c*), is now developing actively from nitrogen fixed by the clover in the first and second seasons.

(*c*) The pasture shown in Plate 2 (*b*) but at completion of growth in the third season. The grass has now become highly productive following applications of 2 cwt. superphosphate per acre in each of the three seasons.

(Photos by courtesy of the Waite Agricultural Research Institute Adelaide, Australia)

PLATE 4. Extremely poor heath land on deep sand in Southern Australia before development under pasture. Right: low mallee (*Eucalyptus*) and dwarf heath vegetation in natural state. Left: the same vegetation logged ready for burning and ploughing.

PLATE 5. Light cover crop of wheat, undersown with pasture of clover, lucerne and sparse perennial grass, following two deep ploughings.

(Photos by courtesy of the Waite Agricultural Research Institute, Adelaide, Australia).

PLATE 6. Pasture of subterranean clover, lucerne and light sowing of perennial grass established under a cover crop on land of type shown in Plate 4. Above shown a year after undersowing mixture in wheat, and below, two years after sowing.

(Photos by courtesy of the Waite Agricultural Research Institute, Adelaide, Australia)

PLATE 7. Conversion of low scrub on poor sandy soil in Southern Australia to a productive pasture by sowing subterranean clover and associated grasses, and by applying superphosphate with small quantities of copper, zinc and molybdenum.

(Photos by courtesy of the Waite Agricultural Research Institute, Adelaide, Australia)

PLATE 8. The effect of molybdenum at the rate of 2 oz. per acre on the development of of clover on molybdenum deficient land.

PLATE 9. Peas (left) and oats (right) in South Australia following a crop of wheat which had depleted the available nitrogen of the soil. The peas yielded 53 cwt. total dry material and 43 bushels of grain per acre, the oats 20 cwt. dry matter and 22 bushels grain per acre.

(Photo by courtesy of the Waite Agricultural Research Institute, Adelaide, Australia)

There is no doubt that much can be done to improve these Mediterranean pastures, and particularly to increase the abundance of the leguminous constituent without resort to the plough. It is, for example, difficult to say what these pastures might be capable of producing if they could only be freed from the intense over-grazing to which they are subjected. There seems little doubt that this measure alone would lead to a luxuriant growth of palatable legumes of many kinds. In addition, considerable response can be expected to applications of phosphate, particularly as regards the leguminous species. Where legumes are not already present in amounts likely to respond to phosphate, surface sowing of seed may be practised.

CHAPTER THREE

RELATION TO SOIL FERTILITY

Soil fertility depends upon a physical condition which favours continuity of supply and an adequate balance of water and air, under a sufficient rainfall or irrigation, and a sufficiency in available form of all essential soil nutrients to provide for the maintenance of production at a level which climatic and economic conditions permit. These factors are closely linked with the supply of available nitrogen; when this is limited, the activities of both microscopic and macroscopic life in the soil are restricted, weathering of the mature soil formation is reduced accordingly, and there is a decrease in the organic matter upon which a good physical condition depends. In many countries, naturally fertile soils occupy only a limited area compared with adjoining regions of deficient soil which may yet be associated with a climate favouring crop growth. These physical resources of climate can in many cases be utilized, firstly for raising livestock, and secondly for crop production through the combined use of suitable legumes and modern artificial fertilizers capable of correcting deficiency in nutrients, including trace elements. Soils which are either naturally poor or have been exhausted by cropping are characteristically low in both nitrogen and organic matter. The cultivation of herbage legumes and associate grasses will ensure improvement of nitrogen content, organic enrichment and the development in due course of a soil structure.

The fertility of many cultivated lands has reached a critically low level and is still declining seriously. In spite of the use of improved varieties and technical improvements in farming, crop yields have already declined below their former level and are continuing downward. In some areas, grassland farming based on legume/grass mixtures, and the use of these in rotational cropping have reversed this trend, but these are in the minority. Depletion of fertility is inevitable under the methods of exploitive farming long practised in many parts of the world. Such methods include continuous cropping to cereals and other non-leguminous cash crops, or their occasional substitution by fallow, legumes for grazing or other type of utilization being absent. Frequent cultivation of the soil breaks down crumbs or aggregates and destroys organic matter, rendering the soil liable to loss of structure and more vulnerable to erosion. The repeated removal of a cash crop with little opportunity for soil recuperation renders inevitable a heavy drain on the soil nutrient supply, which intensifies the loss of organic matter and physical condition.

The primary deficiency responsible for declining crop yields is that of available soil nitrogen. Crops become yellowish, stunted, unproductive and heavily infested with weeds. Such crops respond to artificial fertilizers, such as sulphate of ammonia, but this does not give the lasting improvement in soil fertility which follows organic enrichment and improved physical structure. Results obtained with stubble-sown cereal crops at the Waite Agricultural Research Institute, Adelaide, Australia (Woodroffe, 1949) are shown in Table II.

Table II. Stubble-sown Cereal Grown in Adelaide, South Australia
(in bushels per acre)

	Oats	Barley	Wheat
No nitrogen	43.8	35.2	25.8
2 cwt. sulphate of ammonia per acre	71.2	49.7	35.9
Increase due to applied nitrogen	27.4	14.5	10.1

(Basal dressing - 2 cwt. superphosphate per acre)

Table III gives a comparison between the nitrogen content and nitrate-producing capacity of continuously cropped land and adjoining seeded pasture at the Waite Agricultural Research Institute, South Australia.

Table III. Comparison Between the Nitrogen Content and Nitrate Producing Capacity of Continuously Cropped Land and Adjoining Seeded Pasture in South Australia

	Total Nitrogen	Organic Carbon	C/N Ratio	Nitrate Nitrogen (NO_3)	
				Initial	After 21 days incubation
Continuously cropped with wheat for 15 years from grassland	0.166	2.30	13.8	5.4	5.75
Seeded pasture for 10 years following cropping	0.190	2.29	12.0	18.8	58.85

On land which has become depleted through cropping with wheat and other cereals, a rapidly growing legume forage such as field peas, or an alternative legume with the triple advantage of large seeds, a high growth rate, and capacity for active early fixation of atmospheric nitrogen, may be grown to advantage. An experiment was carried out for 8 years to test the following cycles of land use (each repeated once in the full 8-year period).

1. Wheat/fallow/wheat/fallow (W. F. W. F.)
2. Wheat/oats/pasture/fallow (W. O. P. F.).
3. Wheat/peas (grazed for forage)/pasture/fallow (W. P. P. F.).

The results (Table IV) show the great advantages of utilizing peas under such conditions.

Table IV. Advantages of Using a Fast-growing Legume after Depletion through Cropping

	Yield of Wheat 1st crop (bushels)	Yield of Forage after Wheat (cwt.)	Yield of Wheat 2nd crop (bushels) or Pasture (cwt.)	N as NO_3 in Soil p.p.m.	Mean Net Gain of Protein per year
1. W.F.W.F.	32.69	–	32.69 bush.	11.5	–
2. W.O.P.F.	37.74	20.42	16.84 cwt.	13.8	8
3. W.P.P.F.	43.49	46.11	51.35 cwt.	17.8	105

In those regions of the world in which pastures, based on legume/grass mixtures, and green manure crops can be successfully grown, there is no doubt that they can contribute greatly to the nitrogen status and organic matter content of the soils, and so to soil fertility in general. In a number of regions, such as the drier parts of the Prairie Provinces in Canada, certain Mediterranean countries, many parts of India and other tropical countries, it is impossible to grow the conventional herbage mixtures because of such factors as climatic conditions and lack of adapted species, the nature of the farming systems, and general economic or land tenure problems. Yet even under such conditions, it may be and frequently is possible to introduce short-season legumes as a fertility-restoring break in the rotation. Research should be directed towards finding a way of introducing some type of legume into all possible farming systems.

The original experiments at Cockle Park in northern England at the end of the 19th century revealed that the increased growth of clover on abandoned wheat land following applications of available phosphate led eventually to a darker colour in the soil, increased organic content, improved nitrogen status and a generally higher fertility. This has proved to be a natural consequence of the cultivation of legume/grass mixtures in many parts of the world. The restoration of over-cropped soils, as well as the improvement *de novo* of naturally poor soils, can be economically achieved by sowing appropriate herbage mixtures, first ensuring that deficiencies in soil nutrients other than nitrogen are corrected by the use of appropriate mineral fertilizers. Nitrogenous fertilizers can also be employed with some advantage on pastures provided the value of the increased long-term production obtained sufficiently outweighs the costs involved.

We show in Chapter 5 how herbage mixtures based on legumes and grasses are available for a wide range of conditions throughout the more humid-temperate regions of the world. In Chapters 6 and 7, we discuss how legumes may be grown pure or in association with grasses in tropical and sub-tropical countries, using somewhat unconventional techniques. Pure grass stands are unable to build soil nitrogen significantly as do mixtures with active legumes. Physical structure and the content of available plant nutrients both contribute substantially to soil productivity. Structure is closely dependent on organic content and soil cannot be enriched in organic matter unless sufficient available nitrogen is obtained. The two main sources of available nitrogen are (*a*) inorganic and (*b*) organic. The inorganic salts contain ammonia or nitrate. Sulphate and nitrate of ammonia provide the principal modern source of available inorganic nitrogen and ammonia itself can nowadays be effectively applied to the soil. Herbage legumes on the other hand provide a source of organic nitrogen which has been inadequately explored owing to failure to investigate the scientific and technical factors involved under all possible conditions.

It is often cheaper to grow legumes than to purchase and apply nitrogenous fertilizers, especially when clovers or allied herbage plants capable of active symbiotic nitrogen fixation are grazed by livestock *in situ*. Provided the amounts of nitrogen fixed and the forage yielded per acre are substantial, economic production becomes immediately possible, and nitrogen enrichment of the soil proceeds *pari passu* at little or no cost. Little is known of the comparative efficiency of nitrogen fixation by different legumes, but it is recognized that legumes of value for forage or pasture may fix nitrogen to the extent of about 2 to 3 lb. N. equivalent to 12 to 20 lb. protein for each 100 lb. dry weight of production. The actual value depends on climatic and nutritional factors.

Experiments in South Australia

Experiments on an extremely poor podsolized soil in South Australia, initially low in both nitrogen and phosphate, have shown the rapidity of improvement possible where an appropriate combination of herbage legume and fertilizer is employed. Plate 2 shows the original condition of naturally poor country before development. The soil was a poor sandy type on a retentive clay subsoil. The nitrogen available to the unfertilized pasture totalled only 10 lb. nitrogen per acre, and the phosphate (P_2O_5) 1 lb. per acre; the phosphate content of the soil before development was 0.0006 per cent. These amounts were sufficient only, when availability was considered, to produce 6.49 cwt. dry herbage per acre, or carry one sheep to

PLATE 10. Strawberry clover (*Trifolium fragiferum*) growing in wet, saline conditions in Idaho. Photograph taken June 1941.

PLATE 11. Ploughing under crimson clover (*Trifolium incarnatum*) and rye for soil improvement in Tennessee.

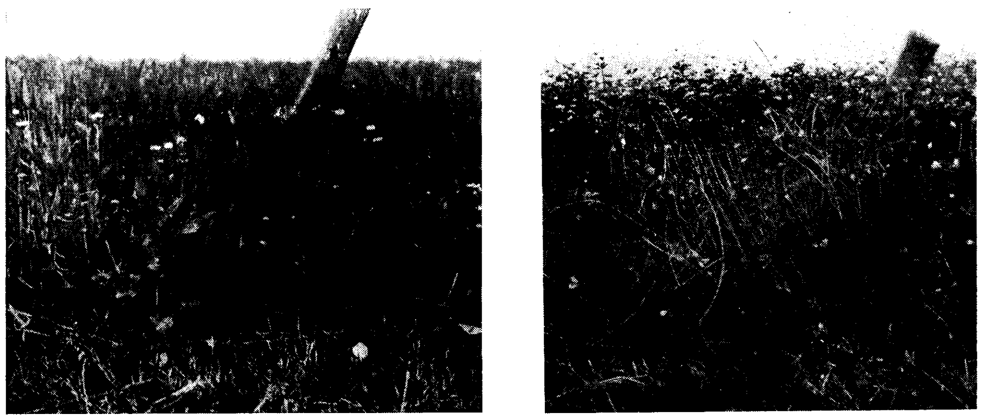


PLATE 12. Effect of phosphate on Persian clover (*Trifolium resupinatum*) in Louisiana. (Left) = no phosphate; (Right) 80 lb. P_2 O_5 per acre.

(Photos by courtesy of the Division of Forage Crops and Diseases, U.S.D.A.)

two acres after clearing in the absence of clover and applied phosphate. Sowing down to subterranean clover and a light seeding of associate grass, together with an annual application of 2 cwt. superphosphate per acre for 3 years, resulted in a pasture which averaged 48.47 cwt. dry herbage per acre over the three seasons, compared with an average of 6.23 cwt. per acre without phosphate. The successive yields with phosphate were 33.18 cwt., 55.67 cwt. and 56.57 cwt. per acre in the first, second, and third years respectively, containing 353 lb., 935 lb. and 1,101 lb. protein respectively, totalling 2,389 lb., averaging 796 lb. and supporting 5 sheep per acre, compared with an average protein production for the three years of 81.27 lb. and one sheep to 2 acres on unimproved land. The production through the use of clover and phosphate was thus ten times the original and this was attained at a relatively low cost.

The phases of improvement are shown in Plates 2-6. The results were obtained over an average growing period of 8 months, commencing in autumn (April), with days just below 12 hours in length, and mean air temperatures of 57° F., falling to 9 $^1/_2$ hours and 47° F. in June-July, extending through an active spring growth period of 12-hour days at 51°-55° F., with completion of growth under dry conditions in November, with 14-hour days and temperatures of 60° F. The mean seasonal rainfall for the three years was 21.46 inches, rising from 2.89 in April to 3.84 inches in July and falling to 1.78 inches in November. This type of winter rainfall climate occurs in countries bordering the Mediterranean, and in the western United States, Chile and South Africa, where a similar level of production could doubtless be obtained. The method of approach has become basic in southern Australia. In addition to the new level of productivity indicated above, the bacterial content of the soil rose from 38 to 400 millions per grammes of dry soil, and its reserve content of phosphate from nil to 67 lb. P_2O_5 per acre.

As already noted, on many other soils in South Australia deficiencies other than phosphate have occurred; the trace elements, copper, zinc and molybdenum, are now used at very low rates with considerable economic success. Similar principles apply where the application of deficient elements or groups of elements result in a normal growth of legumes, to the limits allowed by climate, or climate supplemented by irrigation. Plates 7-10 show the conversion of low heath country to productive pasture, and additional effects on legume growth and subsequent improvement due to appropriate fertilizer application (Plates 11 and 12). The essential factor concerned is the herbage legume and its effective nutrition under the particular conditions of climate which pertain.

Experiments in Puerto Rico

An example of a build-up of organic matter and nitrogen by the use of improved, introduced legumes in Puerto Rico is given by R. M. Smith, George Samuels and C. F. Cernuda (*Soil Science* 72, No. 6 pp. 409-427, 1951). In two run-off erosion plots from which the top 3 feet of the profile had been removed, there is evidence that 4 $^1/_2$ years of growth of *Pueraria phaseoloides* and *Melinis minutiflora*, all of which were allowed to remain on the soil with no disturbance or tillage, built back a total of approximately 1,800 lb. N per acre, with a C : N ratio of about 8. At the end of this period, the surface 3 inches of soil contained 0.15 per cent. N compared to 0.20 per cent. as an average for adjacent normal plots. This build-up appears to represent approximately the maximum total quantity of N which the tropical kudzu might have been expected to fix during this time. At the low level of organic matter and nitrogen represented by a de-surfaced soil, it appears that essentially all of the nitrogen from the crop was turned into stable soil organic matter with a C : N ratio somewhat lower than that of the average, adjacent surface soil.

The same authors state that, apart from areas in Puerto Rico where active erosion is occurring, soil organic matter and nitrogen contents tend to remain stable under certain typical cropping practices. With continuous sugar cane there is apparently an essential balance of organic matter under conditions of good fertilization and full utilization of residues. Coffee with good ground cover and leguminous shade trees; improved close-growing forage crops, especially with tropical kudzu; native legumes in idle land and pastures; and protected woodland; all these are types of land use which can apparently maintain high levels of organic matter. There is considerable evidence, however, that nitrogen-fixing legumes were too sparse in the original virgin forests to have greatly influenced original quantities of nitrogen.

Root systems

In reviewing the effects of legumes on soil fertility one must take into consideration the nature of the root systems of the various species. Although these are so important in relation to the effect of legumes on associated grasses, on the structure, nitrogen content and organic matter status of the soil, and on the yield and vigour of succeeding crops, comparatively little work has been done on the subject. No comprehensive study or review of the subject is known.

It is known, however, that there are great differences in root penetration, from the subsoil exploration by means of the prominent

taproot of lucerne and sweet clover to the shallow though well-branched root systems of white or subterranean clover. Depth of penetration of the root system is a vital factor in relation to drought resistance. T. B. Paltridge in Queensland has shown that lucerne can develop a root system which will explore soil mass to depths of 18 to 20 feet. In cultivated rows, lucerne roots spread horizontally at least 12 feet from the row itself and appear to explore effectively and occupy all but the surface 3 or 4 inches.

Legumes themselves may not develop soil structure to anything like the extent possible with grasses; but grasses may depend upon associated legumes for the nitrogen required to develop the type and extent of root system which greatly improves soil structure. The deep-rooted plants may also have important subsoil effects, as in *Melilotus alba*.

Protagonists of the clover/grass ley have frequently claimed a rapid effect of the root-growth upon soil structure, within 3 years in some cases. Dr. A. H. Lewis, of the Imperial Chemical Industries (I.C.I.), Jealotts Hill Research Station, states that work at several centres in England indicates that a 3-year ley has little effect on the formation of water-stable crumbs in soil; a much longer period seems necessary to produce any marked effect. The main effect is probably nutritional, by supplying nitrogen and perhaps phosphate and potash among other things to crops.

Green manures

Soils can be enriched in nitrogen and organic matter by growing a leguminous crop and turning it into the soil without utilizing the top growth in any other way. The top or herbaceous growth is probably of greatest importance in increasing soil nitrogen, while the root system is important in drawing up the nutrients in the subsoil, particularly in the deep-rooted species. Green manuring at best and under most conditions is an inefficient process and is likely to decrease rather than increase in popularity. No immediate production is obtained from the land, although the costs are as high as for a crop giving an immediate return.

In most annual or quick-growing legumes, the majority of the nitrogen fixed appears in the above-ground or herbage portion; the roots and stubble may contain 10 to 30 per cent. of the total nitrogen. It is generally more economical to use the legume pure or as an associate in a legume/grass mixture for grazing or cut fodder. Although only two-thirds of the nitrogen fixed by the legume is gained by the soil through animal excretion, the loss of the remaining one-third is more than compensated by the advantages in improved soil structure and other characteristics. Although legumes grown

for hay and even for grain produce some improvement of the soil, the gains appear in most cases to be substantially less than under grazing.

In Great Britain and Europe generally, green manures are little used, apart from the growing of lupins, serradella, and other legumes for ploughing under on sandy soils in Germany, Denmark and other countries. The ploughing under of the aftermath growth of 1-year or short-duration leys of the Italian ryegrass/red clover type is the nearest approach in England to green manuring on any scale.

For some little understood reason, green manuring has proved to be of no economic benefit in southern Australia, although great advances have been made through the use of legumes for grazing.

In the south-eastern United States, it is recognized that leguminous green manure crops should be used only when they least interfere with the regular cash crops, that is, when they can be grown as a catch or out-of-season crop. In this humid region of mild winters, where organic matter decomposes rapidly, *winter* legumes fit into the farm programme most effectively. Species of *Vicia*, *Medicago*, *Lupinus*, and *Pisum arvense*, *Trifolium incarnatum* and *Lathyrus hirsutus* are widely used on cotton and maize lands. In the more northern states, catch crops following cereals or sown with them are often suitable. Only in the highly specialized vegetable-producing areas are *summer* legumes used to any extent, sown after the vegetables are harvested in late winter or early spring. Maize following a crop of bitter blue lupins of from 30,000 to 40,000 lb. green weight produces two to three times the average yield. But here also, in Florida, the trend is away from the purely green manure plant such as the non-palatable *Crotalaria* to a multi-purpose legume, such as *Indigofera hirsuta*. A million acres of this species are now grown for forage and green manure.

In Latin America, the practice of ploughing in legumes is virtually unknown, there being a marked prejudice against turning under any crop which might be used for human or animal food. The intercropping of a legume and cereal might be attractive if cheap legume seed were available, and if the legume could provide a period of supplementary grazing (J. A. Rupert).

Trials have been conducted at Potchefstroom Experimental Farm, South Africa, on the effects of alternating maize with sunn hemp, millet, cowpeas ploughed under and cowpeas cut for hay. Although statistically significant increases were obtained in favour of cowpeas turned under, no farmer could afford the cost of cultivating the green manure crop and the loss of a maize crop one year in two. One year of cash crop with one year of green manure failed

to raise yields to the level attained by the addition of phosphate. Cowpeas ploughed under had only a slightly greater effect on maize yields than cowpeas cut for hay, and this slight advantage could not possibly compensate for the loss of a much needed animal feed.

Chemical analyses showed the very rapid decomposition of the organic matter. Within less than a year after ploughing under, there was hardly a trace of the plant residues, and the chances of building up the organic matter content of the soil to any considerable extent seemed under dryland conditions in the western Transvaal to be rather remote. There was at no time a deficiency of nitrogen in the soil even on the continuous maize plots, so that the benefits of green manure may be due to another cause.

Results from the Agricultural Research Institute at Pretoria on rate of decomposition are even more striking, namely, complete decomposition of a ploughed-under green manure crop in 6 to 8 weeks, when conditions are right as regards moisture and temperature. There is no evidence of any increase of the organic matter content of the soil even when cowpeas have been ploughed under every three to four years in rotations lasting 18 years. Results at Pretoria and Potchefstroom agree as regards green manuring on the Transvaal highveld on non-irrigated land. In South Africa, humus appears to accumulate only in badly-drained areas or at altitudes of 6,000 to 9,000 feet. Irrigated land appears to be more promising, since remunerative responses can be obtained from ploughing under leguminous green manures, especially on soils where a nitrogen deficiency already exists.

M. N. Harrison states that green crops grown solely to be ploughed in for their soil restorative value make little appeal to the cultivator in the Sudan. M. F. Rose (1950) has stated, with reference to the Southern Jebels area of Kordofan:

" In the absence of suitable tractor-drawn implements, any system of green manuring presents considerable difficulties; even on experimental farms where ploughs are available the incorporation of a green crop into the soil is well-nigh impossible. With the very rapid drying out of the surface soil, the action of a single mould-board plough, drawn by two unwilling oxen, is merely to tear up a shallow layer leaving no true furrow or furrow-slice. A standing crop is merely displaced, not buried, and a wind-rowed crop has no furrow for final interment. On these heavy clays a further difficulty presents itself in the slow rate of decomposition of the more woody tissues of the plant, and in some cases the intervention of two rainy seasons is essential to effect a final break-down; during the three dry seasons which intervene white ant activity is noticeably increased. At the Kadugli Station all attempts at green manuring in the strict sense have long since been abandoned and the following procedure for dealing with the restorative crop (cowpeas) has been accepted as standard practice: a maximum leaf fall is aimed at before the crop is picked; following this the fibrous haulms are removed by hand for stock feed and the land is then ploughed immediately. In the Gezira, an experiment using *Dolichos lablab* as green manure showed a benefit equivalent to only a moderate dressing of a nitrogenous fertilizer ".

In spite of the great pressure on the land in India, green manuring is widely accepted as a method of improving texture and building up soil fertility, particularly for transplanted paddy, sugar cane, irrigated wheat, and fruit trees (R. L. Sethi). Two important factors in this connection are that the cultivated units are generally too small for safe grazing of a forage legume, and that the use of dung for fuel removes an important source of organic matter from the soil.

A Rice Research Workers' Conference held at Coimbatore in August 1951 recommended that the relative merits of various green manuring crops should be fully tested at various centres both in irrigated and non-irrigated areas, and that breeding should be directed towards the production of improved types. The types to be tried include *Sesbania aculeata*, *S. speciosa*, *Tephrosia purpurea*, *Gliricidia*, *Pongamia glabra* and similar shrubs, *Phaseolus trilobus* and *Lathyrus aphale*.

W. W. Overholt has reviewed some of the requirements and difficulties attending the introduction of green manure legumes into crop rotations under the conditions of a primitive agriculture in Fukien, China (1949). The requirements in a soil-improving crop are:

(*a*) alternative use for human food or fodder;
(*b*) must be grown at a time when the least return can otherwise be secured;
(*c*) seed should germinate readily without scarification and with a minimum of soil preparation;
(*d*) crop should seed readily, be easy to harvest for seed, should reseed naturally - seed should be cheap;
(*e*) growth should be rapid;
(*f*) plants should be low-growing and easily dug into the soil;
(*g*) minimum requirement of fertilizer due to cost and leaching;
(*h*) reduction of great variation noted in nodule formations;
(*i*) plants should be acid-tolerant as liming is not feasible;
(*j*) plants should be free from diseases and pests.

The difficulties are :

(*i*) pressure on the land (suggests growing legumes elsewhere and bringing them to the cultivated land to be dug in);
(*ii*) expense in money and labour (no money available for seeds or fertilizers);
(*iii*) lack of machinery (difficult to work *Crotalaria*, *Sesbania*, *Stizolobium* and similar legumes into the soil without machinery); and
(*iv*) rapidity of decomposition of organic matter.

Overholt states that the only saving factor is that legumes grow well in certain valleys, on land abandoned under shifting cultivation - *Vicia* spp., *Astragalus sinicus*, *Medicago denticulata*, *Lespedeza* spp., kudzu, and *Rhyncosia volubilis*.

Shifting Cultivation

Throughout tropical countries, shifting cultivation may actually represent a form of green manuring, the natural stand of mixed botanical composition being ploughed under (when not burnt) to provide initial organic matter for the new crop sequence. In the Sudan, for example, shifting cultivation or shorter rest periods of one or a few years are the usual methods of maintaining soil fertility between periods of cropping. This method is not entirely a product of laziness and plenty of land to spare. In rotational experiments in the Gezira it has been demonstrated that there is an accumulation of soil nitrates at depths greater than two feet irrespective of cropping and to obtain high yields of cotton the inclusion of a rest in the rotation is as important as the inclusion of lubia (*Dolichos lablab*), the usual leguminous crop. The best results are given by a combination of resting period and lubia and the highest yield of cotton in a three years rotation is from lubia/resting/cotton which gives better results than resting/resting/cotton. Lubia in the year immediately preceding cotton *lowers* the yield of cotton, probably because nitrogen is locked up in the soil. The grain crop, dura, lowers the yield of cotton whatever its place in the rotation and is usually put after cotton where it does least harm with as much rest as possible before the next cotton crop. The eight-course now followed in the Gezira is cotton/resting/dura/resting or lubia/resting/cotton/resting/resting. In Northern Province, nearly half the flooded land is cropped with lubia, either alone or with dura or maize. On " saqiya " similar interplanting is common, and on pump schemes lubia is the restorative crop of the rotation. It seems that lubia has a better effect on soil fertility in Northern Province than in the Gezira (M.N. Harrison).

Mixed cropping

This practice, which has also been called simultaneous rotation, is a relatively common one in village or primitive agriculture in tropical lands. It is a characteristic feature of the agriculture of many parts of India and Africa. In South Africa, the Bantu have always favoured and practised growing cowpeas or other beans with their maize or sorghum (Kaffir corn). The method is now being subjected to experimentation as follows (T. D. Hall):

(*a*) wide spacing of maize 7 inches apart with lucerne sown between the rows at the last cultivation;
(*b*) maize and cowpeas in the same row, widely spaced;
(*c*) in the 35 to 45 inch rainfall areas, maize and cowpeas grown in the same rows, these 3 ½ inches apart.

There are several kinds of mixed cropping and a number of gradations into other types of associate cropping. One can have various mixtures of permanent crops, as in plantations; also in plantations there are the nurse crops to shade and protect the young growing bushes, Herbage and forage plants undersown in cereals represent a form of mixed cropping for a short time, but the chief form of mixed cropping is the growing together on the same land of crops such as cereals and legumes, both of which are harvested at different times for their grain. Mixed cropping does almost of necessity assume hand-harvesting.

This practice has to be considered from a number of angles, as was done by A.K.Y. Narayan Aiyer (1949) in his excellent review of mixed cropping in India, namely, relation to normal crop rotation, soil moisture relationships, utilization of plant foods, method of insurance against loss of crop, relation to insect pests and diseases, the use of mechanical harvesting and labour-saving implements, relation to a balanced nutrition (carbohydrate from cereals and vegetable protein from legume grains), full utilization of space, and economics. This Indian review gives many examples of mixed cropping incorporating cereals such as rice, sorghum, *Pennisetum typhoideum*, wheat, barley, maize, cotton, Italian millet and groundnuts with a wide range of Indian grain legumes (types of *Cicer*, *Vigna*, *Cajanus*, *Phaseolus*, etc.).

Writing of Colombia, J. A. Rupert states that intercropping in cereals would be practicable, e. g. the annual form of *Melilotus officinalis* in wheat, if the weeds could be destroyed. Otherwise the garden peas or vetches with their larger seed have been found to give better stands because the rapid initial growth enables them to combat the weeds.

The fertility cycle

Full utilization by the grazing animal of the legume and its associate grasses in herbage mixtures represents the basis of grassland farming in many countries, particularly Great Britain, Australia and New Zealand. The system merits full investigation in all countries in which it is not already practised. It is the cycle of crop/animal/soil/crop in full operation. At its best, under the favourable climatic and soil conditions of New Zealand, it is possible to achieve production of 14,000 lb. dry matter, equivalent to about 9,000 lb. starch equivalent, with more than 20 per cent. average protein content over a period of years. Under less favourable conditions, e. g. South Africa, very little use can be made of legumes other than lucerne because of the dry, late autumn and winter, and dry, early spring, and also because most of the grasses are dormant in late autumn and winter. Pastures containing clovers in association with ryegrasses, fescues, and cocksfoot are, however, being established widely under irrigation to provide green feed during the dry winter and early spring months. Because of the difficulty of growing legumes under dryland conditions, grass leys in South Africa

have to be well fertilized with nitrogenous fertilizers, for good production from 200 to 400 lb. sulphate of ammonia per acre. Critical experiments in progress indicate that amounts as high as 240 lb. superphosphate and 800 lb. sulphate of ammonia per acre may be profitable.

A well-balanced and correctly managed pasture containing a mixture of legumes and grasses is an excellent source of palatable high-protein grazing in those relatively restricted parts of the world in which they can be grown successfully. The two important factors are the legume, generally white clover or subterranean clover (winter-rainfall environments) in the mixture, and the presence of the grazing animal as an " implement " in the fertility cycle, particularly under conditions where high rates of stocking and long grazing periods can be achieved. It is necessary to consider the nature of the livestock, whether growing, fattening, or dairy beasts, and to replace, through fertilization, the soil nutrients which they remove in the type of animal product for which they are kept. One must also consider losses of nutrients through leaching.

The removal of legumes and their associated grasses from the field for feeding green or for conservation in the form of hay, silage or dried green crop presents quite a different picture. The crop/animal/soil/crop cycle is broken by the absence of the grazing animal; its removal may be compensated to some extent, by the return of all stable and liquid manure to the same land, but this does not always occur. The harvesting of a heavy green crop therefore entails the removal of considerable quantities of soil nutrients, which should in due course be returned to the soil in the form of artificial fertilizers (*see* Table V). Under an all-cutting regime on soils of low to average fertility, this may become quite an expensive item in terms of phosphatic or potassic fertilizers.

Grain legumes are not generally thought to be markedly restorative crops, although they do represent the first step away from a cereal/fallow system or other form of exploitive monoculture. In certain parts of the Mediterranean lands, with their characteristic climate of winter rainfall/summer drought, the fallow year in the cereal/fallow system is occupied to an increasing extent by grain legumes of such genera as *Vicia*, *Cicer*, *Lathyrus*, *Lens* and *Pisum*, harvested for grain and straw. Where this harvesting does not entail pulling the whole plant out of the ground, marked after-effects may be noted in low-fertility conditions as expressed in yields of subsequent cereal crops, especially in combination with phosphate. Experiments in Cyprus indicate that the best results are to be obtained when a grain legume crop is grazed while green. The use of field peas for fattening lambs by direct grazing on the dried vines and pods plus incidental weeds is an unusual technique developed in South Australia, which shows considerable benefits to the subsequent cereal crop, generally wheat.

Table V. Estimated Quantities per Acre of Major Plant Nutrients

[expressed in terms of "Nitro Chalk" (15.5 % N), superphosphate (18 % P_2O_5), muriate of potash (50 % K_2O) and lime ($CaCO_3$), contained in grass of varying yield and lost from the soil under different systems of management (from R. A. Hamilton).]

	Cwt. per Acre											
	" Nitro Chalk " 15.5 % N			Superphosphate 18 % P_2O_5			Muriate of Potash 50 % K_2O			Lime $CaCO_3$		
Yield level - cwt. dry matter per acre ...	30	60	90	30	60	90	30	60	90	30	60	90
Grass grazed by adult fattening cattle	0.3	0.6	0.9	0.07	0.14	0.21	0.12	0.24	0.36	0.05	0.10	0.15
Grass partly grazed by dairy cows and young stock and partly eaten indoors as hay and silage	2.9	5.8	8.7	0.5	1.0	1.5	0.7	1.4	2.1	0.4	0.8	1.2
All grass removed by cutting and sold off farm	5.4	10.8	16.2	1.5	3.0	4.5	2.1	4.2	6.3	1.1	2.2	3.3

In the winter rainfall areas of South Africa, some dryland lucerne is grown in the rotation for 3 or 4 years and grazed off by dairy stock or fattening lambs in August, September and October; it is followed by straw crops, such as wheat and oats for 2 or 3 years. Recently, lupins sown in April/May and turned under in August/September have become most popular because of the great bulk of fodder or green manure produced in a very short time. The land then lies fallow during the hot, dry summer and is sown to wheat in the autumn.

Chapter Four

ALTERNATE HUSBANDRY

There are in all parts of the world examples of field rotations in which crops that remove fertility from the soil alternate with those restoring fertility in the form of nitrogen, organic matter, crumb structure, microbiology and general soil health. We have seen in the last chapter that it is necessary for the recovery or resting break to have a legume in its composition, generally in association with a grass, and that under favourable conditions of soil and climate the greatest benefit can be obtained if the herbage growth is grazed *in situ*.

The extent to which farmers use or can afford to use legumes, with or without associate grasses, for soil improvement depends on their economic and technical status. Farmers dependent on very small acreages of arable crops and particularly cereals for their subsistence or economic return cannot afford to introduce more than 1 year of legume into their rotations, and that legume should produce grain for direct human consumption as a source of vegetable protein. Even arable farmers with larger acreages, such as the East Anglian (Great Britain) barley and sugar beet growers, reduce the legume or legume/grass break to a minimum to obtain maximum return from their enterprise.

Farmers, dependent primarily on livestock and livestock products for their living and using sown pastures or forage crops grown for soilage or conservation, make the maximum use of the legume. Examples are the British ley farming system based on white clover, the systems based on lucerne in the United States, Australia and Argentina, and the use of legumes in irrigated farming systems in Australia, South Africa, Israel and other countries.

It should be noted at this stage that there is a rainfall or precipitation/evaporation limit to the cultivation of legumes in rotation. Below this limit there may be no adapted species, but, more important, at the lower-rainfall limits of cultivation in dry-farming systems, the inclusion of a legume in a cereal/fallow will cause a reduction in the yield of the following cereal crops. This is due primarily to excessive removal of moisture from the soil in the growing and rotting of the legume crop and is one of the important factors in the dry farming systems in the Great Plains of the United States and the southern parts of the prairie provinces in Canada. This does not appear to be true in a Mediterranean winter rainfall environment.

Although theoretically the countries of Western Europe are in a climatic zone in which that form of alternate husbandry known

as ley farming might be practised, there are other reasons why this farming system is not always applicable. In Great Britain, a good deal of permanent grassland can be converted into arable land (with the legume/grass ley in rotation) without much difficulty with regard to soil and water conditions. In Germany, on the contrary, the land suitable for arable crops is already in arable land and the conversion of further grassland into leys first demands that the land should be made suitable for the plough by better drainage. Dr. H. J. Frankena states that these same difficulties are present on a smaller scale in the Netherlands. Although agreeing entirely with the view that the clover/grass temporary ley can greatly improve fertility, he believes it is not always realized that the grassland must be suitable for the plough.

In this connection one must not forget the value of farmyard manure as a fertility-builder, and the availability of this product in northern European countries in which winter stall-feeding is general or in which large livestock populations are dependent upon purchased and imported feeding stuffs, as in Denmark. The fertility-building properties of the legume/grass ley are fully realized in the Netherlands, but this does not mean that it is necessary to follow a fixed rotation. The clover-rich short leys are valuable in rotation with root crops and potatoes on the light sandy soils. In general, the Dutch farmers must give their arable land all the farmyard manure which is available and so there is none for the grassland. When this grassland is used for pasture and receives the very high nitrogenous dressings characteristic of Dutch grassland management, no harm is done, but it is impossible to maintain fields required for hay or silage without farmyard manure.

The Dutch are, therefore, changing from permanent grassland to the ley farming system wherever ploughing can be done. But they are still doubtful as to which system best maintains the organic matter status: (*a*) ley farming, or (*b*) permanent grassland and arable land, with the arable receiving all the green manure and farmyard manure. It is agreed that legumes can play an important part in this connection provided soil and climate are suitable. But, as far as production of fodder is concerned, Dr. Frankena doubts if one can obtain the same dry matter yield with clover/grass mixtures with moderate dressings of artificial nitrogen as from grassland receiving heavy dressings.

Alternate husbandry in Sweden is based on the red clover/timothy ley, which is grown in the arable rotation for hay plus aftermath grazing. Although red clover was first cultivated in Sweden in the 18th century, it was not until the middle of the 19th that the availability of seed of adapted local races made its widespread cultivation possible. Until then the animal fodder was obtained from the natural meadows and from the fallows in the arable rotations. The advent of red clover transformed the whole position.

Far greater quantities of animal fodder of much higher quality became available, and the yields of subsequent crops in the rotation were increased because of the improved soil fertility. Until World War I, Sweden resembled Denmark in being largely dependent on purchased feeding stuffs, but since that time the trend has been towards greater self-sufficiency: and in this, the legumes, red clover, and lucerne where it can be grown, have played a leading part.

Throughout the cultivated lands of the Mediterranean countries, the centuries-old wheat/fallow rotation is still common. Yields are generally low and in parts soil structure is poor and serious erosion occurs. Loss of structure is reflected not only in reduced crop yields but also in serious problems of cultivation, especially when primitive ploughs and other implements are used. In some regions there has been excellent progress towards the inclusion of annual legumes in alternation with the cereals, a great step away from cereal monoculture. Examples are the use of sulla (*Hedysarum coronarium*) in Southern Italy and Sicily, and of *Lathyrus cicera*, *Pisum sativum* and other legumes in Thessaly in Greece. But there still remains an almost complete lack of appreciation of the value in rotation of those pasture legumes and grasses which would improve the fertility of the soil, protect it against erosion, and above all provide abundant and nutritive feed for livestock. Although the climate of the Mediterranean permits considerable development of pastures and fodder crops, the system of land tenure and particularly the small, fragmented holdings must remain a serious obstacle.

The remainder of this chapter will give only a few of the many types of crop rotation which have been evolved on the basis of the principles outlined in this and the preceding chapter. Emphasis will be on new trends rather than on old-established practices already well known. One should here refer briefly to the use of legumes as pioneer crops, before the establishment of a fixed rotation. Examples are the use of *Sesbania*, *Crotalaria* and other legumes in the early cropping phases of the reclamation of alkali land. In the Jura region of Switzerland, *Onobrychis viciaefolia* is an important pioneer crop in stony soils. The two species of *Pueraria* (the kudzu vine) are also important as pioneer cover plants on land which has become eroded and low in nitrogen.

Lucerne is becoming increasingly popular in East Anglia, that part of England which has long practised the Norfolk 4-course rotation. Where there is light drift over chalk and barley, wheat and sugar-beet are grown for several years, followed by 3 or 4 years of a lucerne ley, which is cut for fodder or for sale green to the local dehydrating factory. On the gault clay of the Cambridge University Farm, 5 years of lucerne ley alternate with about 5 years of arable crops. On Lord Iveagh's Elvedon estate on the breckland (light sand), 5 year leys of lucerne/cocksfoot are grown in rotation, cut in the early years and folded with dairy cows from May to October in the

later years, at the rate of one acre per cow for grazing. Here lucerne is giving good economic return and supporting arable cultivation on land which is the nearest approach to desert in Great Britain.

Among the many rotations practised in the United States one may mention those of the north-central states:

Maize or other cultivated crop (1 year)
Small-grained cereal (1 year)

Red clover, or lucerne or *Bromus inermis* (2 or more years).

An unusual rotation is that of barley and *Lespedeza* in Missouri, a 1-year rotation in which the legume seeds itself. We have already referred to winter legumes in rotation with maize in the south-east.

While it would be an exaggeration to say that any farming system in Australia is based on lucerne, this legume is frequently used on the red-brown earths and in places on the mallee soils of the wheat belt. The general practice is to sow from 1/2 to 4 lb. per acre with the wheat; the lucerne readily survives the competition though the plants are small and spindly. The wheat is stripped for grain and the straw stubble grazed and trampled by sheep. During the second and third years a satisfactory stand of grazing lucerne is produced which is of great value to the flocks kept on Australian wheat farms.

Red clover is of value in maize rotations in New South Wales, but perhaps one of the most unusual systems is used in the Murrumbidgee Irrigation Area where rice is the main cash crop. Yields of over 100 bushels per acre are obtained. A pasture mixture of 3 to 5 lb. of *Lolium rigidum* and 2 to 3 lb. of *Trifolium subterraneum* is sown on the dense rice stubble within a few weeks of stripping the crop. The stubble is rolled or trampled down and an excellent pasture capable of maintaining 2 to 4 lambing ewes per acre is produced. This pasture is used for four seasons and ploughed for another rice crop. The farmer can reduce applications of nitrogenous fertilizers by 3 to 5 cwt. per acre (J. G. Davies).

The work in South Africa on the introduction of a ley into mixed farming systems in the highveld is of wide application in many countries which are trying to depart from conditions characterized by monoculture on arable land and overgrazing and erosion on natural grassland. The general sequence of crops may be as follows:

Year	Crop
1st	Ley (seed and hay)
2nd	Ley (silage)
3rd	Ley (silage)
4th	Ley (grazing - ploughed up)
5th	Potatoes
6th	Maize or other crop
7th	Maize or other crop
8th	Legume for silage and winter manuring.
9th-12th	Annual crops for as long as the land permits before turning to ley.

Under the system which has been evolved (H. W. Turpin and J. W. Rowland, 1951), the veld remains productive and stable and the arable lands are given adequate rest under a highly productive ley. The ley is generally a grass ley unless somewhat unusual systems of growing legumes and grasses in separate rows are adopted. The cows in autumn, therefore, have access to an annual legume, such as Hubam clover or cowpeas, since the grazing on the veld, even when supplemented by established pasture, is inadequate for milk production at that time. The production potential of a highveld farm organized and managed in this way is greatly increased.

It is always an argument whether expensive high-producing irrigated lands should be devoted to cash crops, such as tobacco, wheat or vegetables (South Africa), or whether they should in the interests of the fodder resources of the country be devoted at least partly to fodder and grazing crops. They are generally capable of growing heavy crops of high-protein leguminous forage for hay or other use. The presence of a high-yielding animal is an important factor. South Africa has a choice between dairy cows and suckling lambs; the latter do not make full use of year-round fodder supplies.

The irrigation farmer in South Africa can set aside about a third to a half of the available irrigated land for lucerne, and can use the remainder for annual crops, e. g. wheat, barley or oats during the winter, and beans, potatoes and vegetables during the summer. *Crotalaria* (sunn hemp) can be introduced into the rotation on the poorer lands, on half the winter grain lands in the winter and on the other half in the summer. Superphosphate is applied to the sunn hemp and to the following winter crop. After 5 or 6 years, the lucerne will be infested with gramineous weeds and can be ploughed for the annual crops (J. J. du Toit).

Common South African rotations with maize are:

(*a*) Maize/maize/cowpeas;
(*b*) maize/maize/maize/cowpeas;
(*c*) maize/maize/annual grass hay/cowpeas.

An attempt is being made to establish a 6-year rotation in some parts with maize/maize/groundnuts/3-year legume-grass ley. The only legume suitable for such a ley would be lucerne. Occasionally sunflowers may take the place of maize, also dwarf castor. Velvet beans, soyabeans and dolichos are grown in place of cowpeas, particularly in the higher rainfall and hotter areas. On a demonstration farm in the Western Free State, a 12-year rotation is being tried: maize/4-year grass ley/oats/cowpeas/maize/maize/groundnuts/maize/wheat.

Because of the great demand for human food produced from cereals and grain legumes in India, where the population is predomi-

nantly vegetarian, also because of the great pressure on the available cultivable land, the emphasis is on short-season legumes which will permit the taking of two or more crops per year. Legumes are very important. In Uttar Pradesh (United Provinces) for example, nearly 12 million acres (25 per cent of the total cropped area) are cropped to legumes each year, some as the mixed crops already referred to, others as pure sowings. The importance of these crops in the diet of the population rather than a recognition of their beneficial effects in rotation is responsible for the large acreage, even if they may not be as profitable as certain other crops. Some common rotations of Uttar Pradesh are as follows (It should be noted that the monsoon rains fall in July and August) (T. R. Mehta):

1-year sequence

(*a*) Early paddy (June to September) followed by gram (*Cicer arietinum*) or peas (*Pisum sativum*) (October to March/April).
(*b*) Paddy followed by berseem (*Trifolium alexandrinum*)

2-year sequence

(*a*) 1st *year*: early paddy (June to September) followed by gram or peas (October to March April).
2nd *year*: green manure or fallow (June to September) followed by wheat (October/November to March/April).
(*b*) 1st *year*: maize (heavily manured) (June to September) followed by wheat or barley (October to March/April).
2nd *year*: sorghum mixed with pigeon pea (*Cajanus cajan*), the sorghum harvested October/November, the pea in March/April.

3-year sequence

(*a*) 1st *year*: fallow (June to September) followed by wheat (October to March/April).
2nd *year*: sorghum mixed with pigeon pea and harvested as above.
3rd *year*: either 1st year repeated, or fodder sorghum or maize (June-September) followed by gram or peas.
(*b*) 1st *year*: early paddy followed by gram.
2nd *year*: fallow or green manure (June to January/February) followed by sugar cane.
3rd *year*: sugar cane continues until harvested in December, January or February.
This rotation may extend to the 4th year if the sugar cane is ratooned.

The well-known Gezira scheme in the Sudan consists of about 1 million acres of canalized land lying along the Blue Nile to the south of Khartoum which is irrigated by gravity from the Sennar Dam. We are indebted to H. Ferguson, Chief Agronomist in the Sudan Ministry of Agriculture, for this information on the use of legumes in rotation with cotton.

The main function of the scheme is to produce Egyptian cotton, which is the Sudan's chief source of wealth. The soil of the Gezira is a heavy alkaline clay deficient in nitrogen. Irrigation water is available in adequate quantities from July till December, in limited quantity from December till April, and thereafter not at all.

The Gezira is almost within the central rainlands region and the population was originally semi-nomadic, finding adequate fodder for its flocks and herds by seasonal migration. The Gezira scheme has settled a great part of the animal population and these now depend on it for fodder. This is provided by sorghum straw, fallow and canal bank weeds, and by a specially grown crop of dolichos.

In the Gezira, dolichos is usually sown in September. A greater bulk of growth may be obtained from July-sown dolichos, but this is susceptible to a bacterial disease caused by *Xanthomonas phaseoli* which appears in humid weather and causes severe defoliation. The crop is utilized by being cut once or twice for fodder, then harvested for a bean crop, and finally grazed off. It has been established that dolichos suffers from no manurial deficiency in the Gezira. It is damaged by excessive irrigation, but apart from the bacterial disease it is a satisfactory crop in most conditions. It was found to be a better fodder yielder than cowpea and other legumes.

Gezira soils depend on nitrogen fixation to maintain their supplies of nitrate. Fixation of nitrogen by *Azotobacter* plus nitrification of crop debris in fallows appears to be about equal to nitrogen fixation by dolichos in its effect on cotton yields, and the management of the Gezira scheme accept a dolichos crop or fallow to be of equal value in the rotation. There is reliable experimental evidence from long-term rotation experiments at the Gezira Research Farm. These show that dolichos is often superior to fallow, except where cotton follows dolichos without an intervening fallow.

Tables VI.-VIII. illustrate this, and compare the effect of a leguminous crop (dolichos) with a non-legume (sorghum) in rotations.

Table VI. Three-Course Rotation Experiment

Rotation	Mean Yield of Seed Cotton (1926/27-1944/45) k. p. f. [1]	
1. Fallow/fallow/cotton	4.66	(108)
2. Sorghum/fallow/cotton	4.30	(100)
3. Sorghum/sorghum/cotton	3.10	(72)
4. Dolichos/fallow/cotton	4.95	(115)
5. Sorghum/dolichos/cotton	4.55	(106)

[1] k. p. f. = kantar per feddan - 1 kantar of seed cotton = approx. 315 lbs. and 1 feddan approx. = 1 acre.

Soil nitrogen and nitrates have been measured in these rotations. They vary within and between seasons and differences are not often statistically significant. However, nitrogen often occurs in the

order (4, 5), 3, (1, 2) and nitrates in the order (4, 1) (2, 5), 3. The yield of cotton is correlated with soil nitrates, and fallows are of benefit by allowing the reduction of the C : N ratio and thus releasing the nitrate. In the Gezira, any beneficial effect that grasses may have on soil structure is far outweighed by their depleting effect on nitrogen.

Table VII. Combined Rotations Experiment (in part)

Rotation	Mean Yield of Seed Cotton (Average 1936/37 1945/46). k. p. f.	
1. Cotton/cotton	1.56	(47)
2. Sorghum/cotton	2.23	(67)
3. Dolichos/cotton	3.16	(95)
4. Fallow/cotton	2.75	(83)
5. Fallow/fallow/cotton	3.65	(110)
6. Dolichos/fallow/cotton	4.03	(121)
7. Fallow/dolichos/cotton	3.50	(105)
8. Fallow/fallow/fallow/cotton	4.24	(128)
9. Dolichos/fallow/fallow/cotton	4.37	(132)
10. Fallow/dolichos/fallow/cotton	4.20	(126)
11. Fallow/fallow/dolichos/cotton	3.60	(108)

These are mostly phases of longer rotations so that they do not measure long-term effects as in Table VI.

A few experiments have been carried out to find the manurial value of dolichos. Table VIII. gives the mean results of one of these.

Table VIII. Yield of Cotton following Dolichos in Rotation Dolichos/Fallow/Cotton

Treatment	Mean Yield of Seed Cotton (8 seasons) k. p. f.
Dolichos grazed by sheep	5.92
Dolichos grazed by cattle	5.42
Dolichos ploughed in and watered	6.04
Dolichos cut and removed	4.74

Other results in this experiment again indicate that under equivalent manurial treatments the rotation dolichos/fallow/cotton is superior to fallow/fallow/cotton. When considering these results it must be remembered that the response in cotton yield to a dolichos

crop and its value as fodder has to be balanced against the cost of this crop in money, labour and water.

The main rotation practised in the Gezira area at present is an eight course one: fallow/fallow/cotton/fallow/sorghum/dolichos/fallow/cotton. At first sight this rotation appears wasteful of land, but it must be remembered that water and not land is the limiting factor in the Gezira. Fallows after cotton are included to ensure control of certain cotton pests and diseases. The present dolichos area appears to be adequate for the needs of the Gezira, but if livestock were to increase in importance and value, there would be no objection or difficulty (except in delivering irrigation water) in increasing the legume area and reducing the fallows. Closer rotations than the above are practised in some minor cotton schemes where the stress is laid on providing livelihood rather than wealth.

No other legume has been used in rotations in the Gezira, but the results with dolichos are considered adequate to show that legumes are soil improvers in the conditions of the Gezira. With a diversification of the cropping system in the Gezira and more stress on mixed farming, legumes may play an important part as a substitute for weedy fallows, and in increasing livestock production.

Chapter Five

ASSOCIATION WITH GRASSES

Poor soils may be substantially enriched in nitrogen by ploughing in legumes as green manure or by ploughing under the stubble and root growth left after taking a hay, silage or grain crop, but economic advantages are under certain conditions to be gained by grazing legumes *in situ*. Legumes by themselves do not constitute a satisfactory diet for grazing animals nor are they capable of surviving in practice as pure stands, because as enrichment proceeds, grasses and other non-legumes capable of actively competing with and suppressing legumes are favoured. Association of legumes with grasses is thus inevitable and the grass/legume association is the simplest form of desirable pasture. According to nitrogen status and management, such an association may range from pure or almost pure legume to pure or almost pure grass; there are many gradations between these limits.

The association of legume with grass forms the basis of what are known as seed mixtures, from which are produced crops for utilization by the grazing animal or for cutting. Among the older European mixtures, red clover or alsike clover with timothy or Italian ryegrass, and white clover with perennial ryegrass and cocksfoot have been and still are commonly employed. Oats in combination with vetches have frequently provided mixed forage in western Europe. Common weeds of leguminous crops, such as field peas, include wild oats and various species of brome grass. Crimson clover is frequently sown with oats or with Italian ryegrass. Often it is found desirable to establish herbage legumes with a cover crop of oats, rye or barley. Prostrate types of clover are frequently encouraged at the expense of associated grasses by persistent defoliation, provided nutrients other than nitrogen are not limiting. Legumes under such conditions may be favoured by reduced competition from the grasses resulting from nitrogen depletion, as occurs in frequent close mowing.

If grasses without legume complements are sown for pasture, production will eventually suffer owing to nitrogen depletion: although animal droppings return a large proportion of the nitrogen ingested, all of this comes from the soil originally and a further portion also taken by the pasture from the soil is retained by the animal during protein synthesis. A further portion, also taken from the soil, is

lost to the atmosphere in the form of ammonia. If, on the other hand, clovers without grasses are sown for grazing, far more nitrogen than is required by the animal may be fixed by the legume and gained by the soil so that the nitrogen status rises and weeds and volunteer grasses may invade the clover. It is better, therefore, to ensure that desirable grasses are planned as part of the association from the outset so that they may utilize the nitrogen as it is gained, improving the feeding value of the sward and arresting the entry of undesirable plants. If the soil is initially of moderate nitrogen status, most of the desirable grasses adapted to the particular conditions of climate, soil and management may be established in the mixture. If, however, the soil is initially extremely poor, the grasses to be sown require the two-fold characteristic of a tolerance of low soil fertility and a capacity to spread as the nitrogen status rises, either by vegetative activity or re-seeding; and light seedings only of these are permissible. Some grasses associate better with certain legumes than others; moreover, the effectiveness of association will depend on appropriate management, including manuring where necessary.

The nitrogen fixed by herbage legumes is gained by associate grasses largely following ingestion by the animal and subsequent excretion of nitrogen as urea and its breakdown products in the urine. The solid droppings of sheep and cattle obviously assist in improving soil fertility but they contain comparatively little nitrogen and the availability of the phosphorus present is usually rather low. The root systems of legumes are not capable under field conditions of excreting substantial quantities of soluble nitrogenous products into the soil for subsequent absorption by associate grasses. Investigation has revealed, however, that the root systems of leguminous plants contain at any given time only a small proportion of the nitrogen fixed, most of this being translocated to the leaves and fruits. As a general rule, 70 to 90 per cent. of the nitrogen fixed by legumes is located in the portions of the plants above ground and this will either be eaten by the animal or harvested as forage to be fed or sold off the property. Even the small proportion remaining in the roots does not usually become available in the soil until the root nodules and fine rootlets disintegrate or the plant as a whole dies, whereupon the roots break down and release their nitrogen for use by other plants. Under certain conditions, which include restricted light and lowered moisture supply, excesses of nitrogen compared with carbohydrate may so accumulate in the legume that nitrogen flows from the roots of the living plant to the soil. This appears, however, to be the exception rather than the rule.

Excessive shading of herbage legumes by associated grasses or weeds may reduce the light intensity below critical values. This reduces the amount of carbohydrate available to both the host plant

and the root nodule bacteria, thus also reducing the nitrogen enrichment of the pasture; this can be avoided by appropriate management. The leaves of leguminous plants are usually fairly broad and expand to assume a position approximating the horizontal, which enables the leaf surface to receive maximum radiation from the sun. The blades of grasses, on the other hand, tend to be much longer than they are broad, and in a pasture tend to assume a position approximating the vertical. Thus, if grazing is absent or so slight as to result in little defoliation, grass will tend to dominate and shade the legumes, rendering them ineffective contributors to the nitrogen supply of the pasture.

The competitive effects of grasses and certain weeds may be so reduced by low nitrogen supply alone as to render shading negligible. Unfortunately, however, many weeds and grasses of low nutritive value are able to produce a bulk of herbage containing much water and fibre but little protein, on soils of low nitrogen content. It is frequently necessary to remove or restrict such growth by mowing or hard grazing in order to permit the legumes to function. If the cover of grasses and weeds is of exceedingly low protein content and therefore of poor nutritive value, it becomes uneconomical to employ grazing for this purpose as the livestock do not gain even the minimal nutritional requirements; in these cases mowing, cultivation or spraying may be needed to deal with the useless growth. There are other cases where the grass is of sufficient value, if combined with some legume herbage, to permit economic grazing. It is the function of grazing management to govern the relative proportions of clover and grass, and the concentration of protein and other nutrients, in pastures generally.

Blackman (1938) and Blackman and Templeman (1938) have shown that the depression of clover in pastures following the application of nitrogenous fertilizers is due largely to a decrease in the intensity of the light reaching the leaves of the clover, consequent upon increased production of grass stimulated by added nitrogen, and its consequent greater shading effect. Similar results have been obtained at the Waite Agricultural Research Institute, Australia, where applications of nitrogen as nitrate of soda or sulphate of ammonia have been found to depress subterranean clover when grown with ryegrass, but not when grown alone (Trumble and Shapter, 1937, Waite Agricultural Research Institute 1941). In some cases applications of nitrogen may lead to a lowered nitrogen content of the herbage legume. As a practical consequence of this, one can expect legume dominance on soils too poor in nitrogen to develop grass actively, provided appropriate legumes and their root nodule bacteria are utilized, and there are no soil deficiencies other than that of nitrogen. As the nitrogen status of the soil begins to rise with development of the legumes,

and associated grasses begin to exercise shading effects upon the legumes, it may be desirable to minimise these effects by reducing the competition from the grass by appropriate mowing or livestock control. It is probable that grasses compete with legumes in other ways than by shading; for example, the fibrous root systems of grasses are better able to exploit soils for moisture, oxygen and some nutrients, so that an unrestricted growth of grass can suppress legumes both above and below the soil surface. Again, mowing or grazing, in addition to reducing the amount of production above ground, greatly reduce the activity of the root system; close mowing or hard grazing thus has at least a two-fold effect in reducing competition from grasses.

The removal of immature herbage by cutting is effective in reducing the grass content and improving the legume content of mixed pastures because it takes from the land nitrogen gained by the pasture, whereas under grazing conditions about two-thirds of this is returned to the soil in the animal droppings. Mowing at advanced stages of growth depletes soil nitrogen and reduces associate legumes to a greater extent than grazing; in the reverse manner it may eventually encourage legumes by reducing the available nitrogen level and hence competition. Under persistent production additional factors, such as depletion of nutrients other than nitrogen and the development of unfavourable physical conditions of the soil, may operate to the detriment of legumes.

At the end of this chapter we give a number of specimen seed mixtures to indicate the gramineous species with which some of the more important legumes are mixed for pasture, forage and/or green manure in practical farming. Most of these mixtures have been the subject of exhaustive agronomic and practical trial, based on compatibility of species, degree of competition between species, suitability for the purpose in mind, performance and persistence under grazing and cutting conditions, and so on. Readers interested in compounding mixtures for their own purposes should regard those quoted only as a guide, since the environment has a considerable effect on the suitability and performance of any one mixture.

In this connection, H.A. Schoth of Corvallis, Oregon, U.S.A., has stated that the development of mixtures is so variable that it is almost impossible to indicate anything to cover all conditions. In the Pacific, north-west of the United States, for example, innumerable pasture mixtures are used, a high percentage being developed on the ground, to fit particular conditions of climate, soil and utilization. These mixtures may vary from farm to farm.

The type of utilization and the associate gramineous species which are to be used govern the selection of the leguminous species. The uses may be, alone or in varying combinations, grazing, cutting

once or twice only, and repeated cutting over a number of years. The grasses may range from low pasture types, through medium-height semi-pasture types, to tall hay types. To meet these conditions, the legumes may have to be procumbent, low erect, tall erect, or twining; the procumbent types suitable for pasture mixtures in particular require to be rhizomatous, stoloniferous or self-regenerating. In addition, the legumes may have to meet the seasonal requirements of the farmer who grows special-purpose mixtures to provide grazing or forage for cutting at a specific period of the year.

A number of the contributions of British grassland specialists to the bulletin on *Grassland Management*, published by the Ministry of Agriculture and Fisheries for England and Wales, recommend a proper integration of general purpose and special purpose mixtures based on *Trifolium repens* or other grazing legumes. For example, D. J. Columbus Jones of the National Agricultural Advisory Service, Reading, recommends the following three-type scheme for dairy farms in the drier arable country of southern England.

(*a*) To provide good general grazing in April to June, and again in September/October.

		lb. per acre
Lolium perenne	S24	6
L. perenne	S23 or S101	6
Trifolium repens	S100	1½
T. repens	wild white or S184	½

(*b*) To provide a silage crop in May, good grazing in June/July and grazing again either in late autumn or early spring.

		lb. per acre
Phleum pratense	S48	6
Festuca pratensis	S215	6
Trifolium repens	S100	1½
T. repens	wild white or S184	½

(*c*) To provide silage or early hay, with grazing in July/August, and again in early winter.

		lb. per acre
Dactylis glomerata	S37	6
D. glomerata	S23 or S143	6
Trifolium repens	S100	1½
T. repens	wild white or S184	½

V. G. Sprague of the United States Regional Pasture Research Laboratory states that emphasis should be placed upon the selection of simple mixtures (*see* over under U. S. A.) adapted to known

climatic and soil conditions and which can be expected to produce forage for specific purposes such as hay, silage or pasture (for horses, dairy cows, beef animals, sheep, swine or poultry), and for production which fits into the farm programme at favourable times of the year. For example, in the north-eastern region of the United States, *Poa pratensis* and *Trifolium repens* prevail under a system where grazing is fairly continuous from spring to autumn on moderately fertile farm land which is difficult to plough. On more easily ploughable land, and where high soil fertility can be maintained, *Dactylis glomerata* and the Ladino variety of *Trifolium repens* are highly productive. This association will provide excellent midsummer grazing as well as early spring and late summer grazing, and it has the added advantage that the final crop may be harvested for silage. Combinations of *Medicago sativa* and grasses are in a somewhat similar category; while they may be grown primarily for hay or silage, they may be pastured when farm conditions warrant.

The mixing of seeds of leguminous and gramineous species before sowing is a characteristic of the humid temperate lands rather than the tropics. It is, therefore, only natural that the key legumes for use in mixtures are white clover (including Ladino), red clover, subterranean clover and lucerne. It has so far proved difficult to find a tropical legume sufficiently vigorous in growth to compete successfully with the tall tropical grasses. The special techniques which are being evolved to overcome this difficulty are discussed elsewhere (pp. 97, 98).

Seed mixtures for sowing pastures in humid temperate lands have become much simpler since the days of the Swiss writers, Stebler and Schroeter, who, in the latter half of the 19th century, recommended mixtures containing six or eight grasses with two, three or more legumes. These were followed by the Cockle Park mixtures and Elliot's Clifton Park mixtures in Great Britain, the latter containing herbs as well as legumes and grasses. These were adapted to the conditions and standards of the day, when seed quality, germination and weed seed content were not fully controlled, and when seed-bed preparation was unsatisfactory. They were the " shot-gun," " hit-or-miss " or " blunderbuss " mixtures in which it was hoped that conditions would favour at least some of the species sown, although one could never be quite certain which.

As will be seen from the examples quoted below, pasture mixtures are now generally composed of one or two grasses with one or two legumes. This is largely the result of the advances made in the knowledge of seed-bed preparation, seedling establishment, and the other aspects of pasture agronomy. Nowadays, there is generally a good reason why more than one legume is included in a mixture. Red clover and white clover may be sown together,

the red to provide the bulk in initial hay cuts, the white to be the dominant or only legume during the subsequent grazing period. Where the establishment of lucerne is not secure, as in England, a little white clover may be added, ready to act as the legume constituent should the lucerne fail. In Sweden, medium or late red clover is now sown with lucerne in mixtures with grasses, so that the clover can give the bulk in the initial period, while the lucerne is becoming established. Many British mixtures contain early and late strains of the same legume, to provide herbage at different periods of the year.

Rates of seeding have fallen considerably in some countries, where this question has been intensively studied, from the former 35 and more lb. per acre down to 9 lb. per acre or less in some cases. This again is due to improvements in technique, with particular reference to seed cleaning, seed-bed preparation, weed control and an appreciation of plant competition and moisture requirements. The situation has also been affected by the increased availability of improved varieties, including better tillering strains. With the present price of leguminous seeds and the shortage of seed of bred or other improved strains, any progress towards lower seed rates and simpler mixtures will help to promote the greater use of legumes as pasture and fodder crops and in fertility-improving crop rotations. In many countries of Europe a great deal of herbage seed is wasted through excessive rates of seeding.

Rates for crops, such as lucerne and sulla, are still very high in Mediterranean countries, due primarily, it is said, to poor quality of seed, rough seed-bed preparation, and competition from weeds after germination. The rate for lucerne in East Anglia could be as low as 12 lb. per acre, but 18 lb. of lucerne and 2 lb. of cocksfoot are generally used, primarily because of the serious weed competition during establishment. In the drier parts of the United States, the rate for lucerne sown alone is 8 to 12 lb. per acre. In Germany, seed rates for lucerne below 20 lb. per acre are used only in the dry limestone country; elsewhere 20 to 30 lb. per acre is the rule. The standard Swedish hay mixture, red clover and timothy, is generally sown at 20 lb. per acre in southern Sweden, but at 30 lb. per acre in Norrland, due partly to poorer seed-bed preparation and partly to damage to seedlings by fungous diseases under the snow in winter. It is in the drier areas in general that rates of seeding below 10 lb. per acre are recommended, on the principle that the thin stand of seedlings will make better use of the available soil moisture. A possible exception to this may be the popularity of low seed rates in the Midlands and west of England.

Throughout the seed mixtures recommended for grazing leys in humid temperate countries, one has to note the predominance of the various types of white clover (*Trifolium repens*). Apart from subterranean clover in its natural habitat in the Mediterranean and in its new home in southern Australia, no other legume is so important. The chief hindrance to pasture development in the tropics is the absence of any legume of such promise, even among the prostrate types of *Alysicarpus*, *Desmodium* and *Indigofera* or the creeping types of kudzu (*Pueraria* spp.). White clover may be extended out of its normal zones of adaptation by the use of irrigation. It is, for example, coming to be regarded as a key plant for irrigated mixtures in South Africa, where it can have a marked effect on the yield and protein content of the associate grasses. A typical grass/legume mixture recommended for irrigated pastures for milk and fat lamb production is:

	lb. per acre
Phalaris tuberosa	4 1/2
Lolium multiflorum (Italian ryegrass)	4
Trifolium pratense (Chilean)	2½ – 3
Trifolium repens (New Zealand)	2½ – 3

The average protein content of the herbage was 19.6 to 24.9 per cent. from January to March. One morgen gave grazing to sheep and then also to Friesland cows at the rate of 9,148 sheep grazing days per morgen from 19 June, 1947 to 15 December, 1948.

The percentage of hard seeds which occur in legumes has been considered an undesirable feature, but under certain conditions it may be of considerable economic importance. When severe winters cause winter-killing of clover, as in Finland, the progressive germination of dormant hard seeds over a period of years helps to maintain the clover percentage of mixtures without reseeding. In the south-eastern United States, crimson clover frequently failed because of its undesirable characteristic of immediate germination in spring after light rains had provided sufficient moisture for germination but not for the establishment of the seedling plants. The hard-seeded Dixie variety, which has now been developed, promises to eliminate this risk in the use of crimson clover by delaying germination until the appropriate conditions for growth arise in the following autumn.

There are many other questions associated with the composition and establishment of seed mixtures which depend largely on local conditions and farming practices. These include the use of a cover crop, depths of seeding, time of seeding, interval until first grazing, and so on.

Table IX. Seed Mixtures Based on Legumes in Various Countries

Mixture No.	Duration Years	Purpose	Species	Seed rate: lb.per acre	Remarks
England and Wales					
1	1	Hay and aftermath grazing	*Lolium multiflorum*	6	
			L. perenne	6	
			Trifolium pratense (broad red)	4	
			T. pratense (late-flowering)	2	
2	1–2	Hay	*Phleum pratense*	8	
			T. pratense (late-flowering)	5	
			T. repens	1	
3	1–2	Silage and aftermath grazing	*Phleum pratense* S51	6	
			Festuca pratensis	5	
			T. pratense (late-flowering)	4	
			T. repens	1	
4	2–3	Short-duration leys	*L. multiflorum* or N. Z. short-rotation	4	Nos. 4, 5 and 6 are designed for grazing during the first year
			L. perenne	10	
			T. pratense (late-flowering)	2	
			T. pratense (broad red)	4	
			T. repens	1	
5	2–3	Short-duration leys	*L. multiflorum* or N. Z. short-rotation	4	
			Dactylis glomerata	12	
			T. pratense (late-flowering)	3	
			T. repens	2	
6	2–3	Short-duration leys	*P. pratense*	6	
			F. pratensis	8	
			T. repens	2	
7		Long-duration grazing leys	*L. perenne* S24	6	
			L. perenne S23 or S101	6	
			T. repens S100	1.5	
			T. repens wild (white S184)	0.5	
8		Long-duration grazing leys	*L. perenne*	4	
			L. perenne S24	4	
			L. perenne S101	4	
			T repens S100	1.5	
			T. repens S184	0.5	
9		Long-duration grazing leys	*P. pratense*	10	
			T. repens S100	1.5	
			T. repens S184	0.5	
10		Long-duration grazing leys	*D. glomerata* S26	6	
			D. glomerata S143	6	
			T. repens S100	2	
11	3	Long-duration ley for general purposes (Cockle Park type)	*L. perenne*	14	Mixture designed for undersowing and not for direct reseeding
			P. pratense	4	
			D. glomerata	8	
			T. pratense (late-flowering)	4	
			T. repens	0.5	
			T. repens (wild white)	0.5	
12	3	As No. 11.	*D. glomerata* S37	3	
			P. pratense S48	4	
			F. pratensis S53 or S215	6	
			T. pratense S123	2	
			T. repens S100	1.5	
			T. repens S184	0.5	
13	3	Long-duration ley for general purposes	*P. pratense* S48	6	
			F. pratensis S53	6	
			T. repens S100	1.5	
			T. repens S184	0.5	
14	4 <	14, 15, 16 are mixtures based on lucerne	Lucerne	14	
			F. pratensis S125	3	
15	4 <		Lucerne	14	
			P. pratense S51	3	
16	4 <		Lucerne	14	
			D. glomerata	3	
17		Ley for fattening plus production of seed	*L. perenne* (Kent indigenous)	12	S. E. England, particularly Kent
			T. repens (Kent wild white)	4	
18	4 <		Lucerne	18	S. E. England, particularly Kent
			D. glomerata	3	
19	4 <		Lucerne	20	
			P. pratense	2	Undersown under wheat in Kent, England
			T. pratense (broad red)	2	
Switzerland					
20	1–2	Green and dry fodders (Mixtures 20-27)	*Lolium multiflorum*	5	Medium altitude
			T. pratense (early)	20	

Throughout this table it is assumed that seeds of bred and/or certified strains will be used whenever available.

Table IX. Seed Mixtures Based on Legumes in Various Countries *(continued)*

Mixture No.	Duration Years	Purpose	Species	Seed rate: lb. per acre	Remarks
21	1–2		*Phleum pratense*	5	Above 3,000 feet
			Trifolium pratense (late)	12	
			Trifolium hybridum	7	
22	3–4		*Arrhenatherum elatius*	15	Medium altitude
			Dactylis glomerata	10	
			Trisetum flavescens	2	
			T. pratense (Mattenklee)	10	
23	3–4		Lucerne	20	Medium altitude
			T. pratense	3–4	
			D. glomerata	4	
			A. elatius	6	
24	3–4		Lucerne	28	Medium altitude
			D. glomerata	4	
25	3–4		*P. pratense*	5	Above 3,000 feet
			Festuca pratensis	12	
			Trisetum flavescens	2	
			T. pratense	9	
			T. hybridum	3–4	
26	5 –		*A. elatius*	6	Medium altitude
			D. glomerata	4	
			Trisetum flavescens	2	
			Poa pratensis	4	
			Festuca rubra	5	
			T. pratense (Mattenklee)	4	
			Lotus corniculatus	6	
27	5 –		*Phleum pratense*	4	Above 3,000 feet
			F. pratensis	6	
			F. rubra	6	
			Alopecurus pratensis	2	
			Trisetum flavescens	2	
			Poa pratensis	4	
			T. pratense (late)	4	
			T. hybridum	3	
28	1	Catch crops for green fodder, silage and artificial drying. (Nos. 28-33)	Oats	90	28-30 are on autumn fallows
			Vicia sativa	90	
29	1		Oats	50	
			Summer barley	60	
			Vicia sativa	60	
			Rape	2	
30	1		Maize	65	
			Vicia sativa	50	
			Pisum sativum	90	
31	1		Winter rye	90	31-33 are on autumn or winter fallows
			Vicia villosa	70	
32	1		Winter rye	110	
			T. incarnatum	20	
33	1		*Lolium multiflorum*	10	
			T. incarnatum	20	
			Vicia villosa	30	
Germany					
34	1	These four legumes are grown in various combinations, sown under cereals for fodder and green manure in autumn.	*T. pratense*	0–14	
			T. hybridum	3–5	
			T. repens	0–5	
			Medicago lupulina	0–8	
35	1	Over-wintering mixture sown after early cereal and harvested in May next.	Rye	60	
			Vicia villosa	90	
			T. incarnatum	20	
36	1	Green fodder, hay or silage (the Landsberg mixture).	*Vicia villosa*	30	
			L. multiflorum	15	
37	1–2	Sown under early ripening cereal (37-39). Cutting.	*T. pratense*	5–16	
			T. hybridum	0–6	
			L. multiflorum	1–4	
			F. pratensis	0–10	
			P. pratense	0–2	
38	1–2	Pasture	*T. pratense*	4–8	
			T. repens	4–6	
			T. hybridum	0–4	
			L. multiflorum	0–1	
			L. perenne	2	
			F. pratensis	0–8	
			P. pratense	0–2	

Throughout this table it is assumed that seeds of bred and/or certified strains will be used whenever available.

Table IX. Seed Mixtures Based on Legumes in Various Countries *(continued)*

Mixture No.	Duration Years	Purpose	Species	Seed rate: lb. per acre	Remarks
39	1–2	Mountains	*Trifolium pratense*	4	
			T. hybridum	6	
			Festuca pratensis	12	
			Phleum pratense	4	
40	2–3	Cutting	*T. pratense*	4–6	
			T. repens	0–2	
			T. hybridum	3–4	
			P. pratense	4–6	
			F. pratensis	0–20	
			Dactylis glomerata	1–2	
41	2–3	Pasture	*T. pratense*	2	
			T. repens	4–6	
			T. hybridum	0–3	
			P. pratense	2–4	
			F. pratensis	0–12	
			D. glomerata	1–4	
			Lolium perenne	3–6	
42	2–3	Pasture	*T. pratense*	2	
			T. repens	2	
			T. hybridum	5	
			Lotus corniculatus	2	
			P. pratense	2	
			F. pratensis	12	
			D. glomerata	2	
43	4 –	Dry regions	Lucerne	18	
			D. glomerata	2–3	
			Arrhenatherum elatius	5–6	
44	4 –	Moist regions	Lucerne	18	
			F. pratensis or	7	
			P. pratense	2	
United States of America (Pennsylvania)					
45		Permanent pasture, fertile well drained.	*Poa pratensis*	8	
			Phleum pratense	4	
			T. pratense	4	
			T. repens (Ladino)	1	
46		Permanent pasture, moist.	*Poa pratensis*	6	
			P. pratense	4	
			T. pratense	2	
			T. hybridum	2	
			T. repens (Ladino)	1	
47		Permanent pasture, droughty conditions.	*Poa pratensis*	6	
			P. pratense	4	
			Lotus corniculatus	5	
48		As No. 47	*P. pratense*	4	
			L. corniculatus	5	
49		Pasture, silage or hay. Basic mixture for all conditions.	*P. pratense*	4	If seedings are to be established in oats use not more than 60 lb. per acre
			T. pratense	2	
			T. hybridum	1	
			T. repens (Ladino)	1	
		For maximum production in July and August except in poorly drained areas add -	*D. glomerata*	4	
		For fertile, well-drained conditions add -	*Bromus inermis* (Southern strains)	8	
		On poorly-drained areas add-	*Phalaris arundinacea*	8	
			F. pratensis	6	
		For fertile, well drained conditions add -	Lucerne	6	
50		Hay in fertile well-drained conditions (50-54)	Lucerne	6	
			T. pratense	4	
			P. pratense	4	
51			*T. pratense*	6	
			P. pratense	4	
52			Lucerne	10	
			P. pratense	4	
53			Lucerne	10	
			Bromus inermis	8	
54		Annual mixture for silage and hay.	*Sorghum* sudan	15	Soyabeans, sown above 120 lb. per acre
			Soyabeans	60	
55		Mixtures 55-57 grown in rotation for hay, pasture or grass silage.	Lucerne	6–8	
			B. inermis	6–8	

Throughout this table it is assumed that seeds of bred and/or certified strains will be used whenever available

Table IX. Seed Mixtures Based on Legumes in Various Countries *(continued)*

Mixture No.	Duration Years	Purpose	Species	Seed rate: lb. per acre	Remarks
56			Lucerne	8-10	
			Trifolium repens (Ladino)	0.5–1.0	
			Bromus inermis	6–8	
57			*Trifolium pratense* (medium)	6–8	
			Phleum pratense	4–6	
Australia					
58		Irrigated pastures 58-63. Temporary leys.	*Lolium multiflorum* or N.Z. Short-Rotation	6	
			T. pratense	2	
59		Permanent pastures 59-63.	*Lolium perenne*	8–10	
			Dactylis glomerata	6–8	
			T. repens	1–2	
60			*Phalaris tuberosa*	2–4	
			D. glomerata	4–6	
			Bromus unioloides	4–6	
			T. repens	1–2	
61			*L. perenne*	4–8	
			Trifolium fragiferum	0.5–1	
62			*L. perenne*	1–2	
			P. tuberosa	2–4	
			T. fragiferum	0.5–1	
63			*Chloris gayana*	4–6	
			Medicago sativa	4–6	
64		Irrigated pastures, Southern Australia, Mediterranean type climate (64 to 68).	Lucerne alone	4–10	Mainly for hay but grazed lightly in off-season
65		*See* No. 64. Standard mixture for irrigated dairy pastures in Victoria.	*L. perenne*	5–8	
			D. glomerata	2–4	
			T. repens	1–2	
			T. subterraneum (vars. Tallarook or mid-season)	2–3	
66		*See* No. 64.	*Chloris gayana*	2–20	In soils that tend to salinity
			Lucerne	2–5	
67		*See* No. 64.	*Lolium rigidum*	0.5–2	Fat lamb production and dairying
			Trifolium subterraneum (Mt. Barker, Bacchus Marsh or Tallarook)	1–3	
68		*See* No. 64.	*Paspalum dilatatum*	8–10	Fat lamb and dairying in N. S. Wales
			T. repens (Dingee or N. Z. large leaved)		
69		High rainfall, temperate, little or no summer drought (69 and 70).	*P. tuberosa*	1–2	
			T. subterraneum	3–4	
70		*See* No. 69.	*L. perenne*	4–6	
			T. repens or	1–2	
			T. fragiferum	0.5–1	
71		Moderate to high winter rainfall with summer drought	Various mixtures of		
			L. perenne		
			P. tuberosa		
			L. rigidum		
			T. fragiferum		
			Lucerne, and annual medicks		
72		Restricted rainfall with extended summer drought (72 and 73).	Lucerne	1–2	
			L. rigidum	0.5–1	
73		*See* No. 72.	*L. rigidum*	0.5–1	
			T. subterraneum (Dwalganup or Bacchus Marsh) or	2–4	
			Medicago tribuloides	1–2	
74		Mean annual rainfall 20-25 ins. in 7 months of autumn, winter and spring with 4-5 months drought in late spring, summer and early autumn. (74 and 75).	*P. tuberosa*	1–2	Red brown earths
			L. rigidum	0.5	
			T. subterraneum (Bacchus Marsh)	3–4	
			Lucerne	1	
75		*See* No. 74.	*P. tuberosa*	0.5–1	Deep sands formerly under heath
			Ehrharta calycina	0.25–	
			T. subterraneum (Bacchus Marsh)	0.5	
			Lucerne	3–4	
76		Mediterranean climate southern and western Australia No. 76 - short influential rainfall season 4-5 months, (76-78.)	*T. subterraneum* Dwalganup	1	
			(early flowering)	2–4	

Throughout this table it is assumed that seeds of bred and/or certified strains will be used whenever available.

Table IX. Seed Mixtures Based on Legumes in Various Countries *(concluded)*

Mixture No.	Duration Years	Purpose	Species	Seed rate: lb. per acre	Remarks
77		*See* No. 76	*Lolium rigidum*	1–4	
			Trifolium subterraneum Dwalganup var.	2–4	
78		*See* No. 76	*Ehrharta calycina*	10	Sheep grazing (Merinos for wool and crossbreds for fat lambs)
			Trifolium subterraneum Dwalganup var.	2–4	
79		*See* No. 76. Medium length of influential rainfall season 6-8 months. (79 and 80).	Nos. 76 and 77 but replacing *T. subterraneum* Dwalganup with Bacchus Marsh or Mt. Barker mid-season varieties.		
80		*See* Nos. 76 and 79.	*Phalaris tuberosa*	1–3	
			T. subterraneum (Bacchus Marsh or Mt. Barker)	2–4	
81		See No. 76. Long influential rainfall season in excess of 8 months. (81 and 82.)	*P. tuberosa*	1–3	
			T. subterraneum (Tallarook, late flowering)	3–5	
82		*See* No. 81.	*Lolium perenne*	5–8	
			T. subterraneum (Tallarook)	3–5	
			T. pratense	1–2	
			T. repens (*Dactylis glomerata* and *Cynosurus cristatus* may also be added)	1–2	
83		Summer rainfall 30 to 90 ins. p. a. (83-88). Eastern coast N. S. Wales and southern Queensland.	Lucerne alone	8–12	Dairying
84		*See* No. 83.	*Paspalum dilatatum*	10–12	
			T. repens	2–4	
			T. pratense	1–2	
85		*See* No. 83. Short-term ley.	*Lolium multiflorum* or *Lolium rigidum*	5–8	
			T. pratense	2–4	
86		*See* No. 83. Poorer soils, formerly cleared forests.	*Chloris gayana*	2–20	
			T. repens	1–2	
			(also possibly *Paspalum dilatatum*)	10	
87		*See* No. 83. Southern coastal N. S. Wales	*L. multiflorum*	2	
			D. glomerata	4–6	
			T. repens	1–2	
			T. pratense	2–4	
88		*See* No. 83.	*Pennisetum clandestinum*		Runners
			T. repens	1–2	
New Zealand*					
89		Permanent pasture. general purpose.	*L. perenne*	25	
			L. perenne x (short rotation)	10	
			T. pratense (Montgomery)	2	
			T. pratense (broad red)	2	
			T. repens (bred)	3	
			P. pratense optional	5	
			D. glomerata optional	25	
90		Semi-permanent or special purpose (winter and summer)	*L. perenne* x (short rotation)	10	
			L. perenne	3	
			T. pratense (Montgomery)	3	
			T. pratense (broad red)	3	
			T. repens (bred)	10	
91		Permanent and special purpose (winter and summer for northern areas).	*Paspalum dilatatum*	15	Sow in spring or early autumn.
			L. perenne x (short rotation)	3	
			T. pratense (Montgomery)	3	
			T. pratense (Broad Red)	3	
			T. repens (bred)	20	
92	2	Special purpose (winter and summer).	*L. multiflorum*	20	or 40 lb. *L. multiflorum* and no short-rotation
			L. perenne x (short rotation)	6	
			T. pratense (broad red)	3	
			T. repens (bred)	25	
93	1	Special purpose (winter pasture).	*L. multiflorum*	30–60	
94		Oversowing on weak established pastures.	*T. repens* (bred)	2–3	
			T. pratense (broad red)	2-3	
			Modify with *Lotus major* for wet soils and with *T. subterraneum* for dry soils (autumn-sown).		

* In all cases except the last, the figures recommended are considered to be over-generous, and mixtures in which the grass component is reduced by more than 50 per cent. are considered to be adequate with good seed-bed conditions. - J. Melville.

Throughout this table it is assumed that seeds of bred and/or certified strains will be used whenever available.

Table X. Seed Mixtures (in lb. per acre) for Hay Leys in Sweden
(according to Åkerberg, Winkler and Jarl)

Soil Type	Non-peaty Soils												Peat Soils		Perennial Lucerne Leys
Region	Coast and Plains of Southern Sweden							Remaining Parts, exclusive of Norrland			Norrland				Southern Central Sweden
Duration	1 year		2-3 years					2-4 years			2-4 years	Perennial	Long duration	Short duration	
Moisture Conditions etc.	Normal		Normal	Alkaline Normal	Dry	Moist	Gravel or Sand	Normal	Moist	Alkaline Dry	Normal	Normal			
Trifolium pratense medium or late	15	11	12	8	6	9	12	11	8	11	10	8	7	7	–
T. pratense; early	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–
T. hybridum	–	–	2	–	–	7	–	3	4	–	3	3	3	3	–
Medicago sativa (*varias*)	–	–	–	8	10	–	–	–	–	8	–	–	–	–	25
Trifolium repens	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–
Phleum pratense	2	–	7	6	4	7	4	8	5	10	12	13	15	8	3
Festuca pratensis	–	–	3	2	–	4	–	4	5	–	5	6	5	6	–
Dactylis glomerata	–	–	–	–	4	–	4	–	–	–	–	–	–	–	–
Lolium perenne	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lolium multiflorum	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–
Bromus arvensis	–	–	–	–	–	–	4	–	–	–	–	–	–	3	–
Alopecurus pratensis	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–
Poa serotina	–	–	–	–	–	–	–	–	–	–	–	–	–		–
lb. per acre	22	22	24	24	24	27	24	26	24	29	30	30	30	30	28

Note: In southern Sweden, *Phleum pratense* can be replaced by *Festuca pratensis* or *Lolium perenne*, in Central Sweden by *Festuca pratensis*. On dry soils *Bromus inermis* is better suited than *Phleum pratense*.

Table XI. Seed Mixtures for Pastures in Sweden
(according to Elofson, Borg, Wallin)

Legume	Soil Types and Regions												
	Common Soils											Peat or Swamps	
	1			2			3			5		1–2	3–4
	a	b	c	a	b	c	a	b	c	a	c		
	lb. per acre												
Trifolium repens	5	4	6	5	4	6	5	4	6	4	4	4	4
Phleum pratense	6	6	8	10	8	10	12	12	14	12	10	10	10
Festuca pratensis	8	10	6	10	12	4	8	10	4	8	8	10	6
Dactylis glomerata	–	–	–	–	–	5	–	–	–	–	–	–	–
Alopecurus pratensis	–	–	–	–	–	–	–	–	–	–	4	–	–
Lolium perenne	6	5	6	2	2	2	–	–	–	–	–	–	–
Poa pratensis	8	6	8	8	6	8	8	6	8	6	6	6	6
Festuca rubra	–	–	4	.	.	4	3	–	6	6	2	–	–
Agrostis spp.	–	–	–	1	2	1	2	2	2	2	2	2	2
	33	31	38	36	34	40	38	34	40	38	36	32	28

Key:

1 – Coast and plains of south and west Sweden
2 – Remaining regions of south and central Sweden; Southern Norrland
3 – Coast of central and north Norrland
4 – Remaining regions of Norrland

a – Normal moisture
b – Rather moist
c – Rather dry

On well-prepared, weed-free seed beds of suitable moisture content the amount of seed per acre, especially in southern Sweden, may be reduced by 10 to 20 per cent.

Mixtures of Pulses and Cereals in Sweden

For harvesting as ripe grain

(*a*) Oats or barley 70-80 per cent., peas or vetches 20-30 per cent.

(*b*) Broad beans 80 per cent., vetches 20 per cent.

For harvesting as green fodder

(*a*) Rye/hairy vetch mixture at 175 lb. per acre.
Rye 60-75 per cent., hairy vetch 25-40 per cent.

(*b*) Peas/vetches/oats mixture at 250-300 lb. per acre.
Oats 30-35 per cent., peas, vetches 65-70 per cent.
Oats may in this mixture be replaced by broad beans.

Table XII. 2-3 Years' Sown Pasture; Mixed Usage, in the Netherlands

Species and Types	Moist Soils		Dry Soils
Lolium multiflorum	2	–	–
Lolium perenne; pasture type	–	12	–
L. perenne; hay type	12	12	–
Festuca pratensis; hay type	5	–	–
Phleum pratense; hay type	5	–	–
Dactylis glomerata	–	–	15
Trifolium pratense; late	4	–	4
Trifolium repens; cultivated type .	4	5	4
Seeding rate: lb. per acre	32	29	23

Table XIII. 2-3 Years' Grassland for Cutting in the Netherlands

Species and Types	Moist Soils: Mixtures with much clover		Moist Soils: Mixture with less clover	Dry Soils
Lolium multiflorum	5	10	12	–
L. perenne; hay type	–	–	8	
Dactylis glomerata	–	–	–	15
Trifolium pratense (not late)	12	10	5	5
Seeding rate: lb. per acre	17	20	25	20

Table XIV. Permanent Grassland in the Netherlands

Species and Types	Moist Soils	Dry Soils: Clay	Dry Soils: Sand	Intensive Pasture
Lolium perenne; pasture type	8	12	9	16
L. perenne; hay type	6	8	7	–
Festuca pratensis; pasture type....	2	3	2	4
F. pratensis; hay type	2	–	2	–
Phleum pratense	3	4	4	4
Poa trivialis	3	4	2	3
P. pratensis	2	3	4	3
Trifolium repens; pasture type ...	1	1	1	1
T. repens; cultivated type........	3	5	4	4
Seeding rate: lb. per acre	30	40	35	35

Table XV. Perennial Sown Pastures: Mixed Usage in the Netherlands

Species and Types	Moist Soils	Dry Soils
Lolium perenne; hay type	8	8
L. perenne; pasture type	4	8
Festuca pratensis; hay type	6	6
Phleum pratense; hay type	3	3
Poa trivialis	2	–
P. pratensis	2	4
Trifolium repens; cultivated type..	5	5
Seeding rate: lb. per acre	30	34

Table XVI. I and 1-2 Years' Sown Grassland in the Netherlands

Species and Types	Cutting Only	Cutting and Grazing	
Lolium multiflorum subsp. *westerwoldicum*	60	35	10
L. multiflorum	–	15	10
Trifolium pratense (not late)	–	–	10
Seeding rate: lb. per acre	60	50	30

CHAPTER SIX

USE AS ANIMAL FEED

With improving standards of human nutrition in all countries, there is certain to be increasing demand for protective foods, such as milk, butter and eggs. This demand cannot possibly be met unless animal fodders with a high protein content are available, with also the necessary energy foods to preserve a correct protein/carbohydrate ratio. Until recent times, sufficient concentrated high-protein feeds based on linseed, groundnut and cottonseed were available to meet the needs of those types of animals demanding a high-protein ration. Now, the world supply of these feeds tends to decrease because of diversion to other purposes, especially direct human consumption, and at the same time the demand for them as livestock feed increases rapidly. Because of the need to conserve the usual protein concentrates for the non-ruminant animals (pigs and poultry), it is further desirable to meet the protein requirements of ruminants by the use of legumes and their associate species.

Protein-rich herbage

Because legumes are invariably rich in nitrogen and independent of a low status of soil nitrogen, they are regarded as an especially useful and dependable source of protein for animal feeding. The nitrogen in the top growth ranges from 2.1 to 2.8 per cent., averaging approximately 2.5 per cent. By comparison, the percentage of nitrogen in the roots ranges from 1.4 to 2.3 per cent., averaging 1.9 per cent. It is generally assumed that rather more than half the nitrogen in legumes is taken from the air, the remainder being absorbed from available nitrogen in the soil. It has been estimated (Roland McKee, 1948) that in the United States alone more than a million tons of nitrogen are taken by legumes each year from the air; this represents the equivalent of more than 5 million tons of sulphate of ammonia as a soil fertilizer, or above 6 million tons of protein. By contrast, Wilson (*The Biochemistry of Symbiotic Nitrogen Fixation*, 1940) on the basis of statistics published by Lipman and Conybeare, 1936, suggested that the annual loss of nitrogen from the soils of the United States was equivalent to 35 million tons of sulphate of ammonia; only 5 per cent. of this was at the time considered to be replaceable by means of artificial nitrogenous fertilizers.[1]

[1] It should be pointed out that the possible error involved in calculations of such magnitude is great, and that such figures must be used with reserve.

The parts of the legume richest in nitrogen are the seeds and the leaves. Whereas gramineous forages are frequently of low protein content when harvested late as hay, legumes are usually adequately supplied with proteins for livestock feeding, even when harvested at an advanced stage of maturity; in fact, they are often more suitable as food after flowering than earlier, as the protein content may be too high and the fibre content too low in the immature stage for efficient livestock feeding. Legumes not only contain relatively high percentages of protein at all stages, but the protein itself is of unusually good quality; they therefore have an important role as constituents or supplements of animal feeds. Legumes contain large quantities of calcium and phosphorus which are also important in efficient nutrition. They are recognised as providing a superior source of vitamins A and D.

The chemical composition of herbage legumes and grasses grown for comparison under identical conditions of soil and climate and harvested at flowering at the Waite Agricultural Research Institute, Australia, is shown in Tables XVII.-XIX. While it is difficult to ensure identity of developmental phase in such comparisons, the order of the differences has persisted through growth in numerous experiments.

It would, however, be possible to produce other data from Great Britain or New Zealand, for example, which do not show such differences in protein content between grasses and clover. Such comparisons must be related to growth phase and characteristics, and to *total* protein and *total* nitrogen production per acre. Under conditions of good management, *grasses* maintained in an optimal stage of growth can produce just as good results in terms of animal production. Crude protein content of young grass herbage properly fertilized and cut at appropriate intervals for artificial drying in England is about 13 to 18 per cent. Further, a cropping legume, such as wild white clover in the flowering stage, can never be compared with perennial ryegrass in the flowering stage.

Table XVII. Comparison of Subterranean Clover with Ryegrass
(Waite Agricultural Research Institute, Adelaide)

Species	Percentage of Nutrients in Dry Matter							
	N	P_2O_5	CaO	K_2O	Na_2O	MgO	Cl	Soluble ash
	(*a*) legume							
Trifolium subterraneum	3.45	0.61	2.35	4.01	1.54	0.57	1.86	11.83
	(*b*) grass							
Lolium perenne	1.72	0.58	0.71	4.53	0.98	0.39	3.55	9.77

Table XVIII. Comparison of Herbage Legumes and Grasses at Flowering and Completion of Growth
(Waite Agricultural Research Institute, Adelaide)

Species	Flowering Stage				Completion of Growth			
	Crude protein	Crude fibre	N-free extractives	Total ash	Crude protein	Crude fibre	N-free extractives	Total ash
	(*a*) legumes							
Medicago tribuloides ..	29.00	16.23	41.99	11.30	17.19	29.83	43.98	6.52
Trifolium subterraneum	19.50	22.54	44.92	10.81	12.00	27.88	45.55	8.96
Trifolium repens	21.94	15.76	52.17	9.05	12.31	18.58	60.10	7.75
	(*b*) grasses							
Lolium perenne	6.25	29.63	53.80	8.87	5.50	27.86	56.72	8.35
Phalaris tuberosa....	5.25	33.15	51.53	8.65	4.88	30.27	55.12	7.47
Dactylis glomerata ..	5.81	25.97	57.02	8.90	5.38	24.64	58.43	8.80

Table XIX. Protein Content of Seeds, and Stems of Herbage Legumes and Grasses
(Waite Agricultural Research Institute, Adelaide)

Species	Herbage Legumes			Pasture Grasses		
	Medicago tribuloides	*Trifolium subterraneum*	*Trifolium repens*	*Hordeum*	*Phalaris tuberosa*	*Danthonia semiannularis*
Seed	22.88	39.63	30.75	10.50	15.31	17.94
Leaf and stem .	8.00	9.18	11.50	3.25	2.69	5.88

It is the unique chemical composition of legumes which gives them their great food value. The seeds are a rich source of protein in a form which ensures high quality. Legume proteins are mainly globulins; like most vegetable proteins, they may be deficient in certain amino acids such as cystine, which is lacking in many peas and beans. They also tend to be lacking in glutamic acids, arginine and ammoniacal nitrogen. But as a source of vegetable protein, legume protein is no more deficient than other forms of plant protein; legumes fit admirably as a supplement to other sources of vegetable protein.

Like grasses, legumes tend to maintain fairly high concentrations of potassium and phosphorus, but they are usually much richer in calcium and magnesium than grasses. On the whole, legumes are better sources of protein, especially when cut for hay, than grasses. As soil nitrogen becomes limiting, grasses tend to develop reduced concentrations of protein before total production suffers, so that a lowered percentage of nitrogen and other nutrients usually precedes a fall in the total dry yield of grass. On the other hand, legumes tend to retain their chemical composition better, with the result that total yield is more likely to fall than protein content under conditions of soil deficiency. In a pasture of grasses and legumes, the legumes frequently contribute substantially to the feeding value of the pasture. If the legumes grow well, most essential plant nutrients other than nitrogen are present in reasonably adequate and available form. Poor growth of legumes under favourable conditions of climate may be due to suppression by actively competing grasses, or to lack of some nutrient or nutrients essential for the host plant or for symbiotic nitrogen fixation. Abundance of grass in the pasture, however, does not necessarily mean that the feeding value of the pasture is high. Luxuriant grass may be very deficient in protein and other nutrients required by the animal. Its value may be indicated by the animal production from the pasture and by chemical analysis. The establishment of appropriate herbage legumes to improve the feeding value of a pasture will frequently depend upon the investigation and elimination by appropriate fertilizer treatment of deficiencies in soil nutrients.

An animal industry on a high plane of nutrition also requires continuity in fodder supply throughout the year. Legumes may play an important part in filling gaps in the seasonal production of pastures. In Great Britain, for example, lucerne, red and white clover are all used to augment grazing during difficult periods in the summer. Almost without exception, some type of conservation of fodder has also to be practised to meet the demand. Whether this conservation may be haymaking, ensilage or artificial dehydration, the legume alone or in combination with gramineous species can make a great contribution to the yield, nutritive value and digestibility of the material.

The protein content of conserved leguminous fodders is directly related to the age of the stand at the time of cutting, and to the method of conservation. Only in specially favourable circumstances, as when hay has been harvested in very favourable weather or has been dried on fences, racks or tripods, can it be regarded as much more than a roughage, meeting the requirements for maintenance plus a little production. If well done, ensilage and artificial drying can yield a high-protein, balanced, concentrated fodder which will permit of very considerable economy in, if not the elimination of, purchased concentrates.

A decision on the extent to which leguminous pastures or conserved fodders can replace other concentrates for high-producing animals will depend on the specialist in animal nutrition. He will base his ruling for a correct ration on the breed and production of the cow or other animal, and on the protein content and other chemical characteristics of the feed. The variations possible in the protein content of silage or dried green crops are so large that it is quite unwise to attempt to use them for animal feeding without the necessary information as to their quality.

In providing adequate high-protein feeds for high-producing dairy beasts, it is possible to go too far, and to provide excess protein and a deficiency of carbohydrates. The dairy industry in Israel has made remarkable progress towards providing a year-round supply of high-quality fodder, chiefly leguminous, for feeding green in the stalls. As, however, at the same time cow-keepers are still feeding considerable quantities of protein concentrates, it is just possible that a deficiency in energy-providing feeds has been produced. It may be desirable to replace some of the purchased concentrates with carbohydrate feeds to give a better balance. This may well be true in Great Britain and New Zealand also.

As already indicated, pure leguminous forage in common with young grass has an undesirable protein/starch equivalent ratio, lacking enough of the energy required by the animal. This deficiency is, of course, usually overcome by growing them in mixture with grasses, or by adding an energy-rich food when the legumes are fed. This deficiency in carbohydrates also affects the making of legume silage. The preserving lactic acid cannot be formed sufficiently quickly or in sufficient quantity to prevent spoiling; hence molasses must be added, or legumes grown in association with a grass.

The animal husbandman and veterinarian complain that the development of the temporary pasture has created new problems and intensified old ones. On new leys, there is an apparent increase in stock disorders which all arise from some deficiency of the pasture, or from an abnormal reaction of the animal to the herbage. An outstanding example is perhaps bloat in England, the United States and other countries. It is, in, fact one of the difficulties which frequently arise where it is easier to grow good legumes than good grass. Pasture specialists in Mississippi, for example, have so much trouble with bloat that they have to devote much energy to discovering some grass to dilute the luxuriant growth of Ladino clover; drilling heavily manured oats very late in the season is promising and it is remarkable to see the stock grazing systematically along rows of widely spaced grass or oats, and stepping over the clover to do so.

A breeding problem has arisen in sheep grazing in subterranean clover pastures in Western Australia. This concerns a disorder

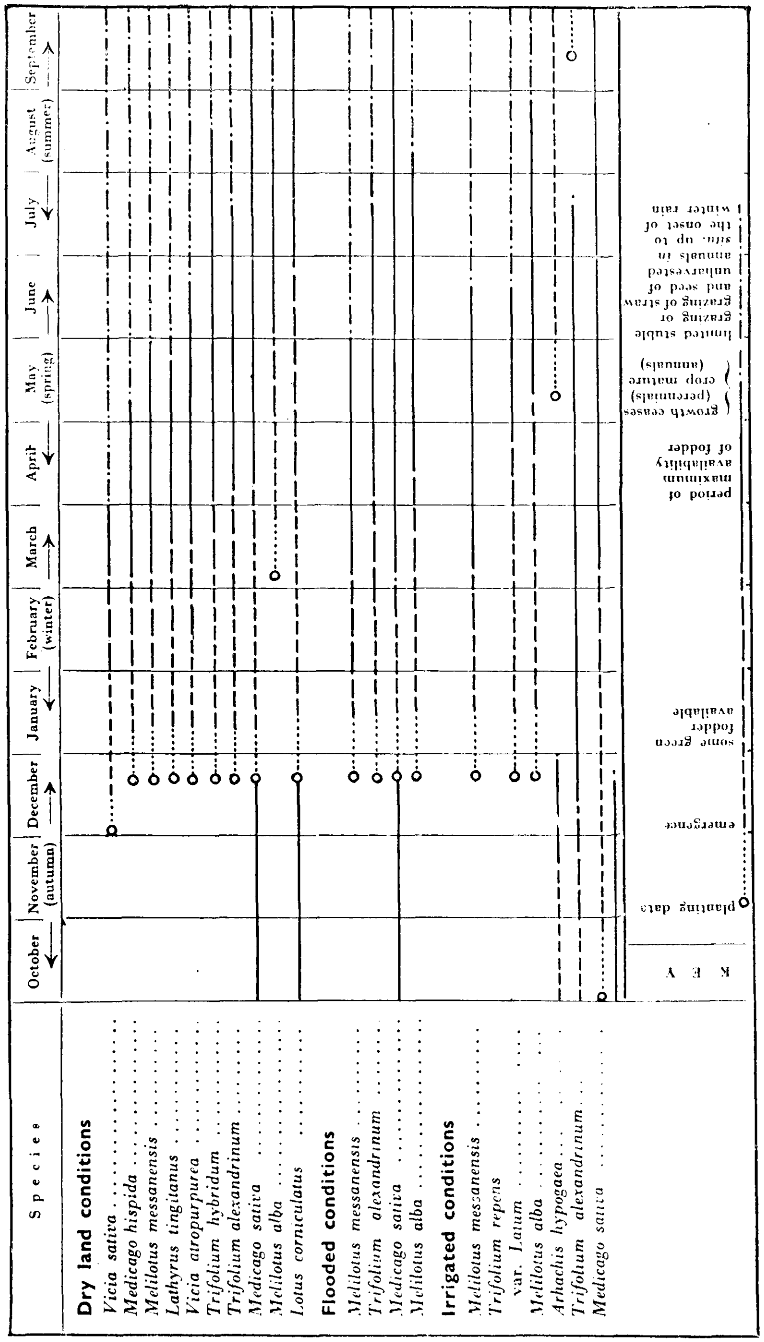


FIG. 2. Chart showing the time of availability of some leguminous plants suitable for fodder production in a winter rainfall environment. (By courtesy of the Department of Agriculture, Cyprus)

associated with stock pastured on the Dwalganup strain of subterranean clover which has led to a remarkable improvement of pastures in the area. Productivity has been increased three or four times and very little cereal cropping is now carried out; stock are maintained chiefly on clover pasture, but receive clover hay supplements during the dry summer and autumn months. There is strong presumptive evidence that the herbage contains some principle (or principles) which is either an oestrogen, or an oestrogen precursor, or a substance which greatly increases the potency of the ordinary oestrogen of the ewe or stimulates its production.

Pastures

To discuss the place of legumes in sown pastures is to discuss the whole basis of modern grassland management. Research during the past three or four decades has been directed towards discovering the species and strains of legumes which are most suitable for and most persistent under grazing conditions, and how they can be established and maintained in association with the grasses competing with them in a sown mixture.

Fundamental to the selection of a grazing legume is a knowledge of the conditions under which it is to be grown and grazed. The pastures of Great Britain, northern and western Europe, the eastern part of North America, and New Zealand are, in general, kept closely grazed and short. In many other parts of the world, and particularly in tropical countries, a "pasture" is necessarily much taller, and it becomes progressively more difficult to find a legume to grow in association or in competition with the grasses.

The outstanding grazing legume of humid temperate lands is, of course, white clover in one of its several forms, with perhaps alsike occupying a very secondary position. Its counterpart in winter rainfall lands, such as South Australia, is subterranean clover. In New Zealand, one can note countless examples of the fertility succession during the developmental phase of both ploughable and unploughable land, from *Lotus* spp. or annual clovers, through subterranean clover to dominance of white clover (J. Melville).

The characteristics, distribution and varieties of white clover are given on p. 333. The general tendency of close-grazing countries, such as Great Britain and New Zealand, is to use the shorter types adapted to intensive grazing, whereas the interest in the United States and Canada is rather in the Ladino type. This is a taller, large-leaved plant, with a long leaf stem, which to a British eye would appear too lax as a type, especially for grazing.

Much is already known and has been written about the role of white clover in pastures. Subterranean clover has already made such a great contribution to the grazing resources in all states of Australia, apart from Queensland, that a description of its establishment and use provided by Dr. J. Griffiths Davies will now be given. This section will be of particular interest to the Mediterranean countries from which subterranean clover originated, and where it still shows great promise of contributing greatly to the very low grazing resources of these countries.

Subterranean clover is used as a pioneer clover on cleared forest, heath scrubs and savannah woodlands. It is also often sown directly into natural or induced grassland swards by light surface cultivation; alternatively it may be sown under a pioneer cereal crop, generally oats, or less frequently wheat. In all instances it is imperative that soil deficiencies be corrected by appropriate fertilizers. Known and well-understood deficiencies are phosphorus, calcium, sulphur, potassium, copper, zinc and molybdenum. Almost every combination of these deficiencies has now been recorded and defined from somewhere in southern Australia.

The clover is generally sown alone in the pioneer phase, but it may be sown with one or sometimes two of the following grasses, the selection of grass depending on climate and soil fertility: Wimmera ryegrass (*Lolium rigidum*); perennial ryegrass (*Lolium perenne*); *Phalaris tuberosa; Ehrharta calycina* and more rarely cocksfoot (*Dactylis glomerata*).

Grazing technique is that of continuous grazing, with some exceptions when the first and more rarely the second season remains ungrazed. Usual farm practice is to sow the clover on land being continuously grazed at about 3/4 to 1 sheep per acre and to take no especial precautions. The reason for the apparent anomaly is quite simple. Subterranean clover is relatively unpalatable in the seedling to flowering stages and stock show preference for other species, especially the Gramineae.

Depending on the duration of the influential winter rainfall season — which may be as short as 4 1/2 months in the 14 to 16 inch rainfall belt of Western Australia, or as long as 10 months in the cool temperate parts of Tasmania and Gippsland district of Victoria — the subterranean clover pastures carry the stock on the naturally dried fodder through the summer period. Here, the importance of the seed supply of subterranean clover is stressed. The longer the rainless hot summer period the more important is the protein supply in the seed. The seed is in the 2 to 4-fruited burr, *a proportion* of which becomes buried up to 1/2 to 3/4 inch in the soil; in heavy crops upwards of 75 per cent. may remain on the surface. This latter

is all easily accessible to all classes of stock — horses, cattle and sheep. Indeed, stock quickly learn how to graze the burr in the surface soil. No actual pawing of the ground is necessary — the stock can readily obtain it by lip action because the density of the burr cover is often so heavy that there is an almost continuous layer in the surface of the soil interspersed with soil particles. This may seem exaggerated, but seed harvesters have actually harvested up to 1 ton of seed per acre. This is not surprising since yields of 4 tons per acre dry matter of subterranean clover are not uncommon at the immediate post-flowering stage, and the seed of the plant may account for 35 per cent. by weight of the total dry matter production at maturity.

It can be readily calculated that 1 ton per acre of seeds, almost all of which could be accessible to sheep, could theoretically carry 4 sheep per acre for 6 months in summer. This allows a dry matter consumption of 10 cwt. per sheep per annum. In addition, of course, there are the dry stem and leaf and the associated grasses so it is not surprising that if the summer is practically rainless a heavy stand of almost pure subterranean clover will carry up to 6 sheep per acre and fatten the sheep.

With increasing length of growing season and decreasing length of dry summer the importance of the seed in the burr falls relative to the green forage stage. Also under these climatic conditions, it is easier to grow grasses in association with the clover and with more summer rainfall dried herbage may be quickly rotted away.

The importance of variety now becomes apparent. The short winter rainfall season calls for the early flowering Dwalganup variety. This will flower and set seed in mid-September and has a high ratio of seed and stem to leaf. The mid-season strains, Mt. Barker and Bacchus Marsh, flower in late October and have a higher ratio of leaf and stem; the late flowering Tallarook strain flowers in mid-November and has a still higher ratio of leaf to stem. Thus, with Dwalganup, the value to stock is to a considerable extent in the seed supply, in the case of Tallarook much less so.

The Dwalganup variety is thus used in areas of Western and South Australia where the moist, warm winters are of 4 to 6 months duration (May-October). The mid-season varieties, Mt. Barker and Bacchus Marsh, are used where the winter season is of 6 to 8 months duration — parts of South Australia, Victoria, Tasmania and New South Wales and parts under irrigation. The late-flowering Tallarook variety is used under irrigation, and where the rainfall season exceeds 8 to 9 months — parts of Victoria, Tasmania and New South Wales. The mid-season varieties are the most extensively used.

A number of other ecotypes of subterranean clover have been recognised, isolated and described but, apart from the four referred to only one or two are of practical importance as yet.

The white seeded variety, Yarloop, from Western Australia is valuable for wet swampy conditions; Clare from South Australia has value because of its early autumn and winter growth, and Mulwala from southern New South Wales for its hardiness and drought resistance in dry winters.

Lucerne as pasture

Lucerne is growing in popularity as a pasture plant in a number of countries, especially the United States, Great Britain and Australia, sown pure or in mixtures with grasses. Current attempts to produce or discover a grazing type of lucerne with a prostrate or rhizomatous growth habit are discussed on page 291. In Argentina, lucerne is used for grazing, or for grazing and hay in alternate years. Provided the grazing is adjusted to the growth habit of the plant and to its need to build-up root reserves during the late summer and autumn, the grazing should be on the "on-and-off" principle, so regulated as to allow the top growth to maintain a height of from 3 to 6 inches. In Germany, it is noted that lucerne and lucerne/grass mixtures cannot be pastured as intensively as grass/white clover pastures, even when the rest periods are adequate for building up the root reserves. In 2 or 3 years the lucerne will have disappeared, particularly in the humid areas. Lucerne/grass mixtures do not contain much lucerne beyond the second or third year if grazed too heavily and frequently. Another point is that animals accustomed to ryegrass/white clover pastures find lucerne pastures unpalatable.

Autumn treatment of lucerne has been the subject of much investigation and discussion. The treatment recommended in North America is to permit the stand to reach a height of 6 to 8 inches and to leave it in this state until the tops are frozen back. In England, the indications are that an adequate rest of about 8 weeks before the last cut of the season ensures an accumulation of plant food reserves. It is recommended that this last cut should be arranged to coincide with the cessation of the season's growth, but the preceding rest period is more important than the last date of cutting. In place of this cut and under the less severe conditions of an English winter, where stock can be kept in the field most of the year, the lucerne stand or mixture may be grazed. February grazing may possibly help to reduce competition from grasses when spring growth begins.

In Germany, optimal conditions for over-wintering and for aftergrowth are obtained with an autumn rest period of 45 to 55 days. In Sweden, three characteristics are considered important in relation to overwintering. Food reserves in the roots should be plentiful and not depleted by recent development of new regrowth, and there

should also be a sufficient number of buds in the crown which will over-winter and produce the first cut next spring. These two requirements can be met either by taking the last cut of the year very early and leaving the final regrowth to be burnt down by the frost, or by taking the last cut just before winter weather sets in and so preventing any shooting of the crown buds. The third important characteristic is to leave a stand of stems which will catch the snow in winter and so give protection from cold winds and severe frosts. This is done either by leaving the last regrowth standing, or by leaving a high stubble (1 1/2 - 2 inches) after a late final cut.

Tropical and sub-tropical legumes for pasture

The fact that for grazing leys the emphasis is on the growth habit of the legume does not mean that taller and less prostrate types cannot be grazed successfully. When sheep were used for improving the fertility of the downland in the south of England, they were folded on mixtures of vetch and a cereal such as rye. Legumes are grazed on irrigated land in South Africa with the results shown in Table XX. Sheep were folded on the cowpeas, soyabeans and velvet beans.

Table XX. Grazing of Legumes and Grasses in South Africa

Crop	Growth Period before Grazing (days)	Times Grazed	Cropping Period (days)	Sheep days per morgen
Vigna sinensis (procumbent)	123	1	148	1 414
V. sinensis (upright)	118	1	135	1 323
Glycine max	99	1	109	1 151
Stizolobium deeringianum	132	1	151	1 233
Crotalaria juncea	58	1.6	96	1 088
Sorghum sudanensis	70	3.8	177	2 303
Pennisetum typhoideum	72	4	220	2 779

Agronomists have for long desired to find a tropical grazing legume, but have achieved little success because of the ecological nature of tropical grasslands, the growth habits of tropical grasses, and the very few tropical legumes which are available to choose

from. Possibly this last difficulty may be overcome by further exploration of the native vegetation in tropical countries, but at the moment the choice seems to be limited to species of *Desmodium*, *Pueraria*, *Alysicarpus*, *Indigofera*, *Stylosanthes*, *Glycine*, *Dolichos*, *Vigna* and *Stizolobium*. At the moment, seed of improved types of these and other genera are not available; it would appear that this is a promising field for the plant breeder to produce types adapted to different environments and uses.

The problem of the legume in tropical and sub-tropical conditions is discussed more fully in Chapter 7, but here it may be said that the trend as far as pastures are concerned is towards cultivation of the constituent legume and grass species of tropical pastures in rows rather than broadcast. The advantages of row cultivation in Queensland are stated by W. G. Robertson as follows:

(*a*) establishment is more certain, particularly in weed infested land;
(*b*) total yield for a 12-month period is greater;
(*c*) yield during winter is greater;
(*d*) production during all months of the year is more uniform;
(*e*) plants commence growth earlier in the spring; and
(*f*) the life of the stand is prolonged because weeds are controlled by cultivation.

Legumes grown by this method include lucerne and *Phaseolus lathyroides*.

Soilage

Legumes are frequently cut, carted to the stable and fed green to the animals. In countries with high labour costs, this system can rarely be afforded. It is much more economical to take the animals to the pasture than to bring cut herbage to the animals. Where labour is available and not expensive the soiling system can be followed, particularly if the land available for pasturage is limited, or where the livestock are of a type which are likely to suffer from exposure to the sun.

Hay

There is little need to elaborate on the methods of growing and harvesting pure and mixed sowings of legumes for hay, since farmers in so many countries are quite familiar with them. The acreage of lucerne cut for hay in the United States, for example, was two million acres in 1899, but had increased to over 17 million

acres in 1949. Yields in the non-irrigated land of the north-central and south-central region average about 2 tons per acre. Where irrigation is common, as in the western regions, the average yield is about 2.5 tons per acre, California topping all the other states with 4.2 to 4.6 tons per acre in three cuts. In Great Britain, the average is 30 cwt. for the country, but 40 to 50 cwt. is common and 3 tons is not exceptional, although not to be encouraged if from one cut. One can readily obtain 3 to 4 tons if two cuts are taken.

Quality is affected by time and frequency of cutting, method and particularly rapidity of curing in the field, and method of storing. Well-made lucerne hay may have more than 20 per cent. crude protein, while badly made, over-mature red clover/Italian ryegrass hay may be as low as 6 or 7 per cent. High-protein lucerne hay in the United States and South Africa is used to make lucerne leaf meal, a product which can be used to some extent as a concentrate, fed with required amounts of carbohydrate.

Many clover and other leguminous species can be made into hay of good quality, provided the natural drying conditions are adequate. Several cuts are taken of berseem in Israel, and one or more of these are made into hay when seasonal conditions permit. Berseem grown for hay under irrigation at "Prinshof", Pretoria, gave five cuts, yielding 28.7 wet tons and 5.5 tons of hay of 16.6 per cent. crude protein.

Investigators in the Punjab studied the effects of cutting intervals of 15, 30, 45 and 60 days on the chemical composition and yield of berseem. Ash, phosphorus and protein contents of the fodder decreased with the longer cutting intervals; moisture, calcium and potash showed a marked rise from 15 to 30 days. Highest yields were obtained with the 45-day interval, corresponding with the active growth period and maximum production of dry matter, which occurred between 30 and 45 days after cutting. The greatest leaf/stem ratio was given by the short cutting interval, and the young leaves were richer in phosphorus, potash and protein than were the older ones.

The Director of Veterinary Services, Onderstepoort, South Africa, has provided data on legume hays:

Crop	Protein Content	Fibre
Vigna sinensis	11.9	20.9
Vicia sativa	13.1	32.6
Arachis hypogaea	10.7	23.6
Phaseolus spp.	9.0	40.0

Silage

As already noted, high-protein material, such as pure crops of lucerne, clover or other legumes, is rather difficult to make into good silage, because of an undesirable protein/carbohydrate ratio. This is overcome by growing them in mixtures with grasses, or by ensiling a gramineous crop at the same time, or by adding molasses or other equivalent conditioner, or by deferring the cutting of the crop until the hay stage or later, so that the protein/carbohydrate ratio will not be so wide, or by wilting.

In Great Britain and Western Europe, the clovers are ensiled with their companion grasses, or vetches and peas with oats, or lupins grown on light sandy lands. In the United States, lucerne is grown in meadow mixtures with brome and other grasses, or ensiled along with maize or sorghum according to the season. In the summer rainfall areas of South Africa, cowpeas, soyabeans, velvet beans, dolichos beans or lucerne are grown with maize or sweet sorghum; in the winter rainfall areas, vetch, serradella, lupins or lucerne are grown with a winter cereal.

The taking of a silage cut is a common practice in modern pasture management, in order to dispose of the surplus growth in the spring. Under British conditions, for example, over 50 per cent. of the seasonal growth occurs in the months of May and June, and most of the remainder in the other 4 months of actual growth. Where the pasture land is laid out in, say, six equal sections for controlled rotational grazing, only five or possibly four can be used during this peak season. If the surplus is cut in a young nutritive stage for silage, the botanical composition, and particularly the clover content of the sward, will not be adversely affected. The cut areas can be returned into the grazing routine when the peak period is past, and will differ little in clover content from those parts grazed throughout. The situation would be quite different if the surplus were taken for hay, as the tall grass growth would tend to crowd out the white clover.

Under the very favourable conditions of New Zealand, silage is regarded as having a place only when, even by judicious selection of species and appropriate management, it is still impossible to fit pasture production to animal requirements throughout the year. By using plants which produce herbage in winter (short-rotation ryegrass) and in the late summer (red clover and/or a summer forage crop), the necessity for silage-making is greatly reduced.

Artificial dehydration

In the past 25 years there has grown up an agricultural industry which represents the conservation of herbage at its most efficient stage of development (R. O. Whyte and M. L. Yeo, 1952). Young green herbage is cut and exposed for quite a short time to temperatures which range from low to very high, in special machines which dry the material on trays or conveyer belts, or in revolving drums or pneumatic towers. With good equipment and management, green herbage can be brought within a matter of minutes or even seconds from 75 to 80 per cent. moisture down to 10 per cent. moisture. It is not our purpose to discuss all aspects of this new industry here, other than to note that a wide range of types of driers exists, that the larger ones require considerable capital outlay, and that prerequisites to economic production are a large supplying area around the drier site, a long season during which green material is available and a uniform rate of production. Since the drier operator requires from the crop specialist this uniform flow of high-quality material, it is quite understandable that the emphasis has come to be placed on legumes, either pure or in legume-rich mixtures, and particularly on lucerne.

The objective of this drying industry differs according to the country. In Great Britain and certain countries of western Europe, the interest is in high protein content, to meet the needs of highly developed dairy industries, to economize in imported concentrates or to make more of these available to non-ruminants. In the United States, the emphasis is rather on vitamin content and general tonic value of dried green crops, partly for use in poultry and pig rations and partly because of the common occurrence of vitamin A deficiency in cattle and sheep on winter ranges and drought areas. The high calcium content of dried legumes is also emphasized. Although it is frequently stated that the United States do not suffer from protein deficiency to the same extent as some countries of western Europe, this is only relatively true. Actually American livestock do not receive the protein recommended by feeding standards. More and more is being used and the supply in sight is inadequate for the theoretical or true requirement. Emphasis is placed on the opportunity to save protein concentrates by the use of forages of high protein content.

The capacity of lucerne to give three, four or more cuts per season, of high quality and of roughly uniform quantity per cut makes it a very valuable crop for the green crop drier. For this reason it has become the key crop for the industry in the United States, and the recent increase of the lucerne acreage in Great Britain, particularly in East Anglia, has been due largely to its use for drying.

The yield and protein content of lucerne are dependent to a great extent on the fertility of the soil, and marked responses in these respects can be obtained by applications of potash and phosphate to soils low in these nutrients. The repeated harvesting of heavy crops of green fodder for drying represents a considerable drain on soil nutrients, and steps have to be taken to replace those removed (Table V).

That these represent a considerable source of animal feed is rather taken for granted; they have not been the subject of any concentrated research, and have not been reviewed as one over-all topic as far as is known. The distinction between grain and seed legumes used for fodder is not generally rigid, but together they include the grain of species of *Vicia*, *Lathyrus*, *Cicer* and *Lens*, and the seeds of species of *Pisum*, *Arachis* and *Vicia* (broad-bean type). The seeds of soyabeans are used to some extent in the United States for feeding swine. A considerable acreage of groundnuts is also harvested by swine in the late autumn and winter. Under pods we would include those complete pods, including the seeds, harvested or collected in some way from leguminous trees and shrubs, most of them growing naturally.

These grains, seeds and pods are generally high in protein, and are therefore used as the concentrated part of the animal ration. Whether improved standards of human nutrition and a greater demand for vegetable protein for direct human consumption will affect the availability of these crops for animal feed is a debatable point.

It is also doubtful to what extent grain legumes are likely to affect soil fertility. Under primitive conditions of harvesting where the plants are pulled out of the ground by hand, there can be little after-effect. This is, of course, necessarily the method of harvesting groundnuts, and considerably reduces their value as a soil-improving crop. The grain legumes are generally cut when mature, shed into grain and straw; presumably they therefore improve the nitrogen content of the soil, but not the organic matter to any great extent.

Chapter Seven

TROPICS AND SUB-TROPICS

Agriculturists have for a number of years been stressing the need for more information on all questions relating to the legume in the tropics, the availability of species and varieties, their incorporation into pasture and fodder mixtures, their use in crop rotation, and their effect on soil fertility under the varied climatic conditions of tropical countries. No attempt has yet been made to review this subject as a whole. The literature is very scattered and quite inadequate for the purpose.

In order to obtain certain basic modern data which might be used within the framework of this book, F.A.O. circulated a questionnaire to all tropical countries in August/September 1951, in the following terms:

1. General statement on the extent to which legumes are used as forage and/or green manure.
2. Economic or climatic factors limiting their wider use.
3. Types or rotations or farming or plantation systems in which legumes are at present, or might with advantage be used as forage, green manure or cover crops.
4. Species which are or might be used (common name, Latin name, varietal name, if any); their individual characteristics, utilization, fodder value, susceptibility to diseases or pests.
5. General agronomy of legume growing (seed rates, mixtures with other plants, number of cuts, grazing technique, if any).
6. Fodder value or toxicity of any herbaceous, shrub or tree legumes occurring in the natural vegetation.
7. Experimental work with legumes, either indigenous or introduced, and varietal improvement work undertaken or proposed.

In this chapter we review the information which has been received, with the following reservations: (*a*). Certain information on legumes in natural vegetation, special techniques of growing leguminous pastures in the tropics, and the use of legumes in certain tropical rotations has already been used in the chapters on these subjects (*b*). All the data provided in reply to question 4 have been incorporated in the descriptions of genera and species in Part II of this book. The text is based entirely on this correspondence without any attempt having been made to review the literature as well. It does, therefore, represent a collation of information published here for the first time, based on correspondence received at F.A.O. between September 1951 and May 1952.

The information has been reviewed on a geographical basis. We believe this indicates the advantages which would accrue from the organization on a regional basis of further work on the adaptation and utilization of legumes in the tropics. Staffs are so small and facilities so restricted in practically all the tropical countries we review that such regional collaboration would lead to great economy of time, effort and plant material. The tropics are, in general, 100 to 150 years behind the humid temperate zones in understanding the significance of legumes, in maintaining soil fertility and in feeding animals. Great possibilities await an energetic, co-ordinated approach to these problems, if only to clear up certain conflicting opinions in different parts of the world (*see* pp. 10,11).

WEST INDIES

Bahamas

Legumes are used on a limited scale for soil improvement. *Leucaena glauca* may at times comprise one-fifth of the palatable vegetation of the unimproved lands used for pasture. The land is rocky; only where it has been reclaimed can legumes be grown as green manure. Improved pastures are lacking. Shifting cultivation is practised by the peasant farmers; the bush is felled and burnt, and maize is sown, followed by sweet potatoes. In the second year the same crops may be repeated, or they may be followed in the second or third year with a mixed sowing of sorghum and pigeon pea. Certain reclaimed areas are now growing onions, followed by maize; farmers are being urged to grow peas instead of maize whenever possible.

Species: *Crotalaria spectabilis*, *C. mucronata*, *Vigna sinensis*, *Stizolobium deeringianum*, *Cajanus cajan*, *Leucaena glauca*, *Stylosanthes hamata* (*see* Part II for further particulars).

Species being tested: *Vigna sinensis* var., *Lespedeza* sp. *Pueraria phaseoloides*, and a grazing mixture of *Leucaena glauca* and Guinea grass (*Panicum maximum*).

Sowing: *Crotalaria* spp. at 10-20 lb. per acre. Cowpeas at 1 to 1 $^{1}/_{2}$ bushels (60 to 90 lb.) per acre.

Cajanus cajan is sown 3 or 4 feet apart when grown as feed crop, closer as shade or cover.

Grenada

Legumes are little used for forage or green manure and are generally absent in grasslands and pastures. Species commonly used as shade and cover for young cocoa are pigeon pea, *Gliricidia maculata* and *Cassia reticulata; Tephrosia candida* is being tested. Chemical analyses have shown the feeding value of *G. maculata* and it is palatable to cattle and other livestock. The Department of Agriculture is encouraging its planting as low hedges through grass fields and around the borders of fields to provide high-protein fodder and nitrogen-rich vegetable matter for mulching. Factors limiting wide use of green manures and cultivated fodders are high labour costs and general unsuitability of most of the land for mechanical cultivation.

Jamaica

The Department of Agriculture is attempting to evoke interest in legumes for fodder and for incorporation with grasses in grazing mixtures. A few estates use legumes as green manure in citrus orchards. Some of the promising adapted types are very hard to establish and recover slowly after cutting or grazing.

Rotation on alluvial soils on savannahs:

Tomato	Autumn
Maize, red peas and Cassava (mixed)	March/April
Sweet potatoes	September
Cajanus cajan	April
Grass (4 to 5 years)	Autumn

Rotation in higher lands with terra rossa:

Maize, pulse (soyabeans or cowpeas)	(1 year)
Maize	
Pulse	
Maize	
Pulse	
Grass (3 years)	

The legumes in these rotations are strictly cash crops. Promising legumes: Lucerne, *Indigofera endecaphylla*, *Indigofera subulata*, *Centrosema pubescens*, *Pueraria phaseoloides* and *Desmodium adscendens*, *I. subulata* grows best with *Panicum maximum*, *I. endecaphylla* best with *Melinis minutiflora*, forming a vigorous growth with a thick mat.

Six cuts per year can be taken from lucerne over a 2-year period, three cuts from kudzu for the same period (both in pure stands). The other legumes can be cut three or four times per year. *I. endecaphylla* is persistent under grazing. Kudzu requires to be grazed lightly on an 8 to 10-week cycle. The Department has evaluated six species in terms of seasonal yield of nutrients and yield of green matter, as well as for effect on soil structure and fertility. The persistency, frequency of grazing and carrying capacity of legume/grass mixtures have been observed.

Puerto Rico

Only in the more progressive districts are legumes used to any extent as forage and green manure. Their wider use is limited by lack of species and varieties well adapted to the island, and by the general backward condition of agriculture (for crops other than sugar cane); the farmer is either uninterested or uninformed on the value of legumes in agriculture. Legumes might profitably be used in association with grass to provide pasture and fodder for livestock, and for soil building and erosion control in combination with the annual clean cultivated crops. Species: *Pueraria phaseoloides*, *Indigofera endecaphylla*, and *Stizolobium deeringianum*. *Canavalia ensiformis*, *Desmodium intortum*, *Dolichos lablab*, *Centrosema pubescens* and *Indigofera hirsuta* may become important. The species in the natural vegetation are poor and non-productive.

Experiments on introduction, breeding and evaluation of legumes are in progress at the Federal Experimental Station, Mayaguez, Puerto Rico, and regional tests, management, soils and agronomic studies at the Agricultural Experiment Station of the University of Puerto Rico, Rio Piedras, Puerto Rico.

Trinidad

Legumes are not used extensively in peasant agriculture, although benefit would be expected. The land is usually left fallow after the crop has been harvested and until preparation begins in the following year. A green manure would be of particular value in the rice fields. The main factor limiting the spread of legumes is the disinclination of the peasant farmer to plant crops with no direct cash or food value, and the lack of knowledge regarding their effects on soil fertility.

In plantation agriculture, legumes are being increasingly used as cover under citrus and coconuts. All soils are nitrogen deficient,

and climatic conditions favour weeds, especially grasses. Perennial species, such as *Pueraria phaseoloides*, are generally employed.

Formerly, the sugar estates used leguminous green manures extensively for turning in between rows of plant-cane and for broadcasting in fallows before ploughing. The legumes were annuals, such as *Canavalia* spp. *Phaseolus mungo*, *Phaseolus radiatus*, *Crotalaria juncea*, *Stizolobium aterrimum* and *Vigna sinensis*. Seed supply was always a problem and the practice is now discontinued.

Species; the above and *Tephrosia candida*, *Stylosanthes guianensis*, and *Indigofera endecaphylla*.

CENTRAL AMERICA

Honduras

Legumes are little used, apart from trees for shade and cover in coffee plantations. Farmers are unaware of their value, seeds for sale or free distribution are scarce, and methods of controlling diseases and pests are inadequate. No crop rotation is practised.

Species of potential value: *Cajanus cajan*, *Dolichos lablab*, *Stizolobium deeringianum*, *Vigna sinensis*, *Desmodium*, *Crotalaria stricta*, *Phaseolus communis*.

Because of ease of cultivation, adaptability to any soil, and resistance to drought, diseases and pests, pigeon pea is increasing in popularity. The *Desmodium* sp. grows wild and would be excellent for forage if its seeds were not so slow in germinating. The present study of the natural flora may yield valuable information regarding new legumes. Selected varieties of kidney bean are giving double the normal seed yield.

Guatemala

Demonstrations are organized to show farmers the benefits of green manures, and experiments are projected for the use of legumes in rotation with maize and with citronella. Owing to the range of natural conditions, there are a number of suitable legumes e. g.,

clover and vetches in the cool mountainous regions, and the species of *Desmodium* and *Phaseolus* at the coast. There is a need for a survey.

Maize is grown in rotation with a weed fallow. It is difficult to introduce a well-balanced rotation, but farmers might at least be persuaded to mix legumes with the maize at the last sowing. In the cool regions, wheat yields may be trebled if grown in rotation with vetch; the legume can be sown with 350 lb. of fertilizer 6-12-4 and ploughed under before the next wheat crop. Another method consists in sowing red clover and Hubam clover with the wheat. It would also be desirable to use legumes in rotation with rice.

Nicaragua

Legumes are not raised for fodder, but many species occur naturally.

Pacific Coast: *Calopogonium mucunoides*, *Rhynchosia minima*, *Desmodium scorpiurus*, *D. canum*, *D. nicaraguensis*, *Tephrosia decumbens* and *Phaseolus atropurpureus* (all seasonal, and dry during dry season, December to May).

Atlantic Coast: *Desmodium scorpiurus*, *D. canum*, *Calopogonium mucunoides*, and *Vigna vexillata*.

Farmers are unaware of the value of legumes as green manure and are unaccustomed to growing them for fodder. Many legumes appear to be well-adapted, including *Dolichos lablab*, cowpea, soyabean, *Alysicarpus rugosus*, *Lespedeza* and Ladino white clover. Demonstration plots have been set out.

El Salvador

Although experiments at the National Centre of Agronomy have shown increases of 50 to 100 per cent. in the yield of grain crops following legumes for green manure, greater use of legumes is limited by economic and climatic factors; the cultivators are obliged through economic necessity to grow food crops such as maize, *Tripsacum dactyloides* or rice; there is a 6 months dry season from November to April. As against this, one notes the good and cumulative effects of green manures on maize yields (Tables XXI. and XXII.),[1] also that *Dolichos lablab* sown in October and November can withstand drought and keep green throughout the dry season.

[1] These two tables give comparative data for various rotations tested at the National Centre.

The seed rates of legumes which have been promising in trials for grain or green manure are:

Species	Seed rate: (lb. per acre)	
	Grain	Green Manure
Cajanus cajan	15	30
Vigna sinensis	25	45
Canavalia ensiformis	35	60
Rhynchosia phaseoloides	12	25
Dolichos lablab	25	35
Stizolobium deeringianum	35	60

It is recommended that cultivated lands should be sown to legumes at least once every 3 or 4 years, preferably used as green manure.

The provision of a year-round supply of fodder of uniform quantity and quality is one of the difficult problems in animal feeding in the tropics. The recommendations of the National Centre of Agronomy are therefore of considerable interest (Fig. 3).

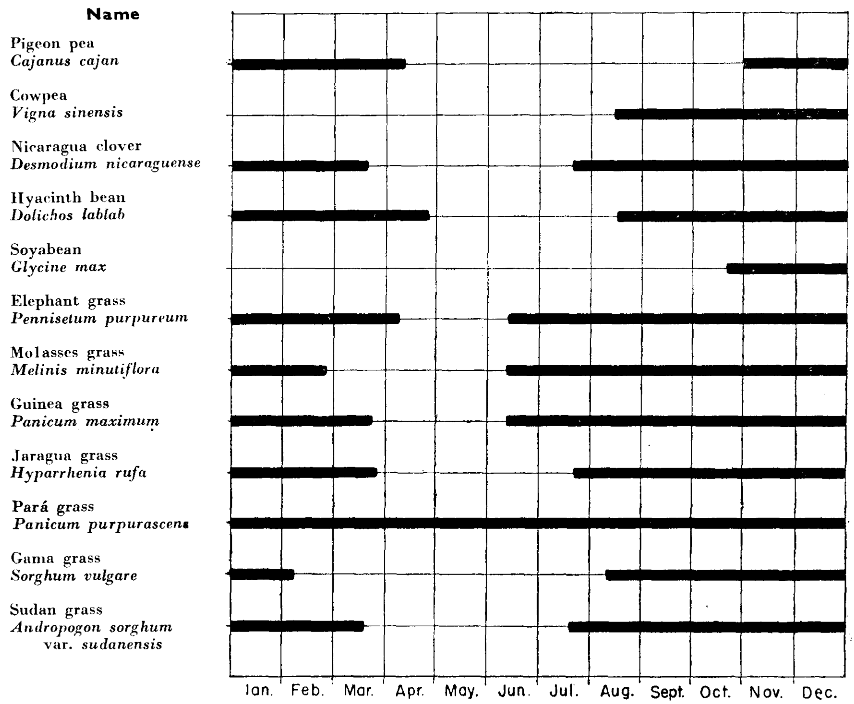


Fig. 3. Growing period of some legumes in El Salvador.

Table XXI. Maize Yields in Rotation and Continuous Sowing over 5-year Period

Crop	Yield in Gold Quintals per Manzana				
	1946	1947	1948	1949	1950
Maize preceded by *Dolichos lablab*..................	36.62	Crop lost	56.00	51.50	62.00
Continuous maize	36.62	59.00	54.34	26.83	28.64

Table XXII. Comparison of Yields of Improved Varieties of Maize and Rice Grown in Rotation and as Continuous Crops in El Salvador

Crop Sequence	Grain in Gold Quintals per Manzana (= 1.72 acres)	Increment under Rotation System
Maize/cotton	41.65	12.26
Maize/rice	44.91	15.52
Maize/beans	51.34	21.95
Rice/cotton	32.75	5.35
Rice/maize	31.37	3.97
Rice/beans................................	30.84	3.44
Continuous rice...........................	27.40	—
Continuous maize	29.39	—

SOUTH AMERICA

British Guiana

Legumes are rarely used as forage or green manure, and no manure is returned to the land in the existing farming systems, apart from the use of inorganic fertilizers in sugar cultivation. Land is usually cropped under a monoculture system, with short intervening periods of fallow. Shifting cultivation is practised in the marginal areas. Pastures are generally over-stocked and over-grazed, and any legumes present do not survive or spread.

Local conditions of flood and drought and the elaborate drainage systems necessary make farmers reluctant to devote any land to legumes. In the main peasant crop — rice — no legume has been found to grow successfully in the low-lying fields, which are not easily drained and are, therefore, inundated for varying periods during the rainy season. Coconuts, citrus and other orchard crops are barely economic because of low prices and high labour costs. This, plus the fact that crops could not be established in large estates by manual labour alone, is a deterrent to the cultivation of green manures. Growers of root crops generally obtain good cash returns from their crops, and prefer to use a short fallow or to practise shifting cultivation.

There is a need for greater use of legumes as forage. Natural pastures are generally poor in or devoid of leguminous species, and the protein content of the grass flora is very low. But the legumes would have to grow in association with grasses under the arduous conditions of exposure, flood and drought.

Species: *Calopogonium mucunoides*, *Centrosema pubescens*, *Indigofera endecaphylla*, *I. subulata*, *I. suffruticosa*, *Pueraria phaseoloides*, *Alysicarpus vaginalis*, *Teramnus labialis*, *Stylosanthes gracilis*, *Crotalaria latifolia* and *Dolichos lablab*. *Desmodium triflorum* and *Alysicarpus vaginalis* occur sporadically in natural pastures, prefer higher ground out of swamps, but are unable to survive or spread. *Pithecellobium saman* makes a good shade tree and its leaves and pods are relished by cattle; it encourages lush growth of grass in its shade.

Colombia

Legumes are little used because the farmers are unaware of their advantages for fodder and/or green manure. Use is also restricted by scarcity and high cost of seed. Stock grazing in the grass dominant meadows have a craving for protein, eagerly seek out the few legumes present, and so eradicate them. In addition to increasing the availability of legumes to grazing animals, they could also be grown more in rotation to provide hay or other fodder and to improve soil fertility.

Species used to a very limited extent are:

(*a*) fodder, pasture for cattle, hay on stock farms in cold regions, 6,500 to 10,000 feet above sea level; *Trifolium repens*, *T. hybridum*, *T. pratense*, *T. incarnatum*, *T. dubium*, *Medicago hispida*, *M. denticulata*, *M. sativa*;

(*b*) forage in temperate and hot regions, sea level to 6,500 feet; species of *Desmodium*, *Stizolobium*, *Calopogonium*, *Pueraria*, *Vigna*, *Crotalaria*;

(*c*) trees of which the foliage and fruits can be utilized for stockfeed occurring in regions where the soil is sandy and desert-like; species of *Gliricidia*, *Machaerium capote*, *Vachelia farnesiana*, *Ceratonia* and *Prosopis*.

Species thought to have potential fodder value in the various temperature zones of Colombia are listed in Table XXIII.

Table XXIII. Legumes for Fodder in Colombia

Latin Name	Climatic Region Where Grown (temperature in °C.)
Medicago sativa	10 to 25
Medicago hispida denticulata	10 to 20
Trifolium pratense	12 to 23
T. incarnatum	10 to 23
Melilotus alba	12 to 25
T. repens	10 to 25
T. hybridum	10 to 25
T. amabile	10 to 20
T. dubium	10 to 22
Lespedeza sp.	14 to 24
Vicia villosa	14 to 24
V. andicola	14 to 20
Lupinus sp.	14 to 24
Desmodium uncinatum	16 to 26
Stylosanthes guianensis	18 to 25
S. guianensis, var. *subriscosus*	18 to 25
Zornia diphylla	18 to 28
Vigna sinensis	18 to 30
Desmodium discolor	20 to 30
Cajanus indicus	20 to 30
Calopogonium mucunoides	20 to 30
Crotalaria ritens	20 to 25
Stizolobium deeringianum	20 to 30
Arachis hypogaea	20 to 30

Peru

To meet the needs of an expanding dairy industry, the growing of forage legumes, particularly lucerne and clovers, is becoming increasingly widespread. They are grown in all parts of the country; lucerne is grown on 90 per cent. of the total area planted to forage

legumes. The use of legumes for green manure is very limited, since the high-nitrogen organic fertilizer, guano, is available in abundance.

Economic factors do not limit the cultivation of legumes; among climatic factors, altitude is the most important, the limit for crop cultivation being about 11,500 feet above sea level. In most parts of the country, lucerne fields are used repeatedly for 6 to 8 years in succession, the fields are then sown to cereals for 2, 3 or 4 years, and the cycle then returns to lucerne. In many places along the coast and in the mountains, lucerne alternates with sugar cane.

The two types of lucerne, coastal and mountain, are grown below and above the 3,300 feet line respectively. The most common clover is *Trifolium repens*. Seeding rates are 30 lb. per acre for lucerne and 25 lb. per acre for white clover. The yield of lucerne along the coast is 12 to 14 tons of green fodder per cut with four to five cuts per year; in the mountains it is 10 to 12 tons per cut, with three to four cuts per year. In the Department of Arequipa, eight cuts can be obtained per year.

There are several species of legume growing naturally in the mountain areas, the most important being *Medicago carretilla*. None of the wild legumes is toxic to livestock.

Peru is, of course, a large producer of lucerne seed and exports considerable quantities.

Ecuador

As legumes are not widely known and therefore not frequently cultivated by farmers, the Ministry of Economy hopes to disseminate information and conduct experiments. Certain large landowners have also planted small trial plots. The authorities feel that it is this lack of knowledge and experience rather than climatic and economic factors which is primarily responsible for the limited use of legumes. Because of the varied topography of the country and the irregular precipitation along the coast, careful initial experiments are essential.

Although there is no basic rotation using legumes, on one farm in the Province of Guayas beans are grown after rice merely as a change-over of crops with little idea of soil improvement. In the Province of El Oro, soyabeans were formerly grown in rotation, but this has now ceased. Although experiments indicate the value of *Crotalaria* as cover in cocoa plantations, the practice has not been adopted. Green manuring is practised in coastal regions, where one crop is grown repeatedly and the land is subject to heavy rainfall and active erosion.

Preliminary experiments with lucerne indicate excellent possibilities for this crop in areas where the climate is uniform, the soils are suitable, and artificial irrigation is available. Many varieties of beans are available, and the area under them might be greatly increased, particularly on the large rice plantations in the Province of Guayas. A propaganda campaign with species of *Crotalaria* is desirable, as is education in the proper technique for growing and using tropical kudzu (*Pueraria phaseoloides*), a plant of great promise for normal cultivation for the re-vegetation of wastelands. The cowpea (*Vigna sinensis*) is another legume which could well be introduced into rotations throughout the rice, cotton and maize areas of the coastal provinces. Farmers are planting cowpeas after ploughing the rice stubble, and the crop is used for human food.

Research into methods of sowing and on the general agronomy of legumes is desirable. Cowpeas are generally sown mechanically at about 60 lb. per hectare. When sowing is done by hand, it is customary to sow at distances of 21 inches. The same distance between rows is used for the smaller varieties of beans, but from 17 to 26 inches for kidney bean. The rate for soyabeans is 25 to 30 lb. per hectare and the drill widths as for cowpeas.

AFRICA

Sierra Leone

Legumes are not used for fodder or soil improvement, as the traditional system of agriculture is by bush fallow or shifting cultivation. Groundnuts are grown for human consumption and export; various beans and peas, including pigeon pea, are grown mixed with rice or other crops, but rarely pure. The Department of Agriculture has experimented with various legumes as cover crops; only *Pueraria phaseoloides* has been of real value as a fodder and cover crop. *Tephrosia candida* and *Calopogonium mucunoides* have both been discarded.

Nigeria

Western Provinces. Legumes are not used to any extent by peasant farmers, although their value as fodder and still more as cover and green manure has been demonstrated by the Department of Agriculture for many years. Intercropping and the bush fallow make

the introduction of green manuring difficult, and the small stock population due to tsetse fly and bush growth in the high rainfall area of the Western Provinces does not stimulate any local interest in fodder production.

Legumes are extensively used as cover on government farms, and green manuring has proved adequate to maintain basic fertility in the rotations on Moor Plantation, Ibadan, shown in Table XXIV.

Table XXIV. Rotations at Moor Plantation, Ibadan, Nigeria

	1st Course	2nd Course	3rd Course	4th Course
A	Early Maize Late Okra Cowpeas	*Stizolobium* Late Maize	Yams Cassava Cowpeas	Cassava (cont.) *Stizolobium*
B	Early Maize Cassava Cowpeas	Cassava (cont.) *Stizolobium*	Yams Late Okra Cowpeas	Early Maize *Stizolobium*
C	Early Maize Late Okra Cowpeas	Early Maize *Stizolobium*	Yams Cassava Cowpeas	Cassava (cont.) *Stizolobium*
D	Early Maize Late Okra Cowpeas	Groundnuts Tobacco	Yams Cassava Cowpeas	Cassava (cont.) *Stizolobium*

Species: *Pueraria phaseoloides* and *Centrosema pubescens* are used for covers of a year or more, and the latter also for mixture with grasses for grazing; *Stizolobium aterrimum* has a vigorous trailing habit suitable for a quick temporary cover, but is free from serious disease and has a high fodder value; *Crotalaria* sp. and *Cajanus cajan* are less used and *Stylosanthes gracilis* is under trial. There may be useful species in the native flora.

Seeding rates: *Pueraria* 6 lb. per acre; *Centrosema* 8 lb.; *Stizolobium* 28 lb. on 6 foot ridges or 40 lb. on 4 foot ridges; the last may be cut at 1 to $2^1/_2$ ft. for hay or silage, or dug in as green manure.

Eastern Provinces. Legumes are grown for grain, and any manurial value from nitrogen fixation or the burying or burning of residues is incidental. The local system of land tenure with apportioned farming areas, communal ownership of land, the custom of annual firing, and lack of fences do not facilitate the use of legumes. Only leguminous shrubs can survive the dry season. Natural bush or

planted fallows have in the acid sand areas proved to be more efficient soil restorers than planted legumes. The idea of manuring land or feeding animals is quite alien to the people, and legumes cannot be introduced unless they will provide food for man in the first instance. No existing rotation uses any legumes for forage, green manure or cover crop. Only oil palm plantations might use a legume as a cover crop, but experiments have shown that leguminous covers are not superior to natural regrowth.

In Bamenda, members of the bean family fit well in local systems and are planted twice a year during the rainy season. They are found as an intercrop through maize, cocoyams, sweet potatoes and other food crops. Their value as a cover is slight, but the stems and foliage have some manurial value. Spreading varieties of soya-beans could be used as a cover but they are not popular as a food because they take so long to cook compared with ordinary dwarf beans.

Species grown in Bamenda include: *Phaseolus vulgaris* (dwarf and climbing) and *Ph. lunatus* (28 lb. per acre); *Vigna sinensis* (20 lb. per acre); *Glycine max* (20 lb. per acre); *Stizolobium* sp. (50 lb. per acre); *Cajanus cajan* (10 to 20 lb. per acre depending on spacing); *Tephrosia candida* and *Sesbania*. In the remainder of the region, the following are used: *Arachis hypogaea*, *Vigna sinensis*, and *Dolichos bulbosus*.

New introductions and green manuring systems have been tested at Abakaliki and Nkwella. *Stizolobium* is the best green manure crop at Nkwella, with the following reservations: (*a*) on the best soils where *Stizolobium* grew well it is doubtful whether after 5 years there is a serious fall in fertility (*b*) on medium soils where both *Calopogonium* and *Stizolobium* grow well, a fall in fertility would be delayed by using these green manures, and (*c*) on poorer soils below the level of fertility required by *Stizolobium*, *Calopogonium* did not maintain fertility in a continuous cropping system. The poorer the soil, the more rapid the fall in yield.

On better soils, therefore, these manures do appreciably delay the fall in fertility which seems inevitable under continuous cultivation. Economic continuous cultivation is possible only over a period of 2 to 6 years depending on the grade of the soil. A deep-rooted fallow for 2 or more years with the incorporation of organic manures or artificial fertilizers is necessary to restore the balance.

Northern Provinces. Although leguminous and non-leguminous crops for fodder, forage or green manuring have been planted on the experimental and demonstration farms of the Department of Agriculture, they have not been adopted by the agricultural community. In the first place, the general peasant practice continues to be one of shifting cultivation; the land is cropped with grain crops and groundnuts or cotton (and in the southern areas with yams and cassava

also) until its fertility begins to drop, when it is allowed to lie fallow for a period of years. In certain densely populated areas, as around Kano city, cultivation is practically continuous, but fertility is here maintained by manuring with dung and household refuse and by kraaling cattle on the fields.

In the second place, climate in the form of a generally short growing season precludes catch cropping and no peasant farmer is likely to grow a whole year's crop for no tangible cash return. When he does not have enough land to allow for an adequate fallow period and where, at the same time, the cattle population is insufficient to allow adequate maintenance of fertility by occasional kraaling and a shortened fallow, as occurs in the south-east of Benue Province, the peasant might conceivably be interested in planting special fallow crops, but here little progress has been made. An incidental use of a legume as a regenerative crop is found in the Idoma Division of Benue Province, where pigeon peas for food are planted as the last crop before the land is allowed to fallow. The pigeon peas survive for several years, not the full length of the fallow, and their regenerative value has been demonstrated.

The cattle population of northern Nigeria belongs to nomadic pastoralists of the Fulani tribe, who have little desire for a settled life and no incentive to plant fodder crops. The " farmers " own considerable numbers of small stock, which are fed on cut fodder from the bush or given seasonal fallow grazing. The cut wet fodder contains *Alysicarpus vaginalis* and the dry season feeding includes the dried haulms of groundnuts and cowpeas. A numerically small section of the farming community has adopted a local form of " mixed farming " under the influence of continual visits and encouragement by departmental staff. The time has not yet come when these farmers can be persuaded to plant their own pastures or even to improve existing bush pasture, although the ultimate objective is mixed farms, self-supporting in livestock feed.

No convincing proof has yet emerged that leguminous crops have a better regenerative value than non-leguminous in northern Nigerian conditions. There is a phosphate deficiency which must be satisfied before nitrogen supply becomes limiting, and it is probable that more general utilization of phosphatic manures will be necessary before a stage is reached when the legume will be of value for its nitrogen-fixing qualities alone. The question whether a legume rather than a non-legume should be used for fallow purposes must at present depend on whether there is any advantage other than nitrogen fixation to be gained from the use of the legumes.

It is probable that a shortening of the necessary fallow period in peasant systems of shifting cultivation could be achieved by a planted rather than a natural fallow. The best fallow would possibly be a grass/legume mixture, but it has not yet been possible to find

suitable legumes for mixing with the grasses, of which the most valuable are the deep-rooted *Chloris gayana*, *Pennisetum purpureum* and *Panicum maximum*. Legumes being considered include *Pueraria phaseoloides*, *Stizolobium deeringianum*, *Alysicarpus vaginalis* and *Centrosema pubescens*, the last of which appears to make a stable mixture with *Cynodon plectostachyum*.

Reports on the following experiments may be available soon:

1. annual legumes as green manures in arable rotations, to maintain fertility (with or without the use of farmyard manure) under continuous cropping, or at least to lengthen the cropping period possible between fallows;
2. comparison of annual and perennial leguminous and non-leguminous plants to ascertain the degree to which they can assist in shortening the fallow period after an arable cycle;
3. legumes for maximum fodder production;
4. effect of interplanting legumes through grain crops on fodder and grain yields;
5. effect on seed and haulm yields of *Stizolobium* of providing supporting stakes;
6. effect of farmyard manure on fodder yields from legumes.

The trials at Yandev, South Benue Province, have shown that pigeon pea is equal in regenerative value to large planted grasses, such as *Chloris gayana* and somewhat better than natural vegetation; and that a fallow of about 3 years after a cropping cycle of 3 years is required to maintain fertility if no farmyard manure is used. A new series of trials initiated at several stations in the past 2 or 3 years is to determine the optimal duration of fallow after a 3-year arable cycle without manure; these trials are supplemented in several cases by " type of fallow " trials in which various leguminous and non-leguminous fallows are compared with natural regeneration; the first reliable results will not be available for at least 5 or 6 years.

French Equatorial Africa

A number of replies to our questionnaire have been received either direct from officers in parts of French Equatorial Africa (Middle Congo, Gabun, or Oubangui-Chari), or through Prof. J. Trochain of the Institut d'études centrafricaines, Brazzaville, and Montpellier, Hérault, France. The general trend of the replies is very similar to that already noted for Nigeria, as will be seen from the following extracts. One correspondent makes the point that much can be expected by introduction of new species and varieties, and that the most obvious source of such material would be the relatively unexplored flora of Brazil, a country with which exchange and other contacts do not at the moment exist.

Table XXV. Nutritive Value and Digestibility of Fodder in Northern Nigeria

Crop	Type of Fodder	Ash	Protein		Fibre		Fat		Carbohydrate	
		T [1]	T	D [2]	T	D	T	D	T	D
Stizolobium deeringianum	Hay (2,500-4,000 lb. per acre).	6.5	11.2	7.3	34.2	14.7	1.6	0.8	46.5	33.0
Cajanus cajan	Dried young plants	8.6	20.9	16.5	27.4	16.1	5.5	3.7	37.6	26.7
Alysicarpus vaginalis	Green fodder	9.2	18.3	12.5	31.8	14.9	3.8	2.1	36.9	25.8
Phaseolus aureus	Hay	14.0	11.9	6.9	27.3	15.3	1.7	0.8	45.1	30.2
Arachis hypogaea	Hay [3]	10.6	8.3	5.9	33.6	17.5	1.1	0.9	46.4	33.4
Glycine max	Young green fodder	10.3	7.9	5.5	30.7	12.6	2.7	1.4	48.4	33.8
Vigna sinensis	Hay	6.8	10.9	7.4	27.4	12.9	1.8	0.7	53.1	36.1

[1] Total in dry matter
[2] Digestible
[3] Yield of hay positively correlated with nut yields, generally 1,000 to 2,000 lb. per acre

The present cultivators still have sufficient land to practise shifting cultivation, burning the fallow growth for manure; green manures are quite unknown to them, and they are never used in the cacao and oil palm plantations of the Gabun. In this part of Africa, animal husbandry is almost non-existent, apart from farmyard poultry, sheep, goats and a few pigs. The sheep and goats may occasionally receive leaves of manioc, banana, sweet potato, papaya and young oil palm.

There are a few European colonies in the Gabun and Middle Congo; they are not yet mechanized in Gabun and although they have reached this stage in Middle Congo the agricultural practices have not become stabilized to the extent of knowing which legumes to grow for green manure or when to sow them, etc.

The authorities believe that it would be possible to increase the yields of the peasants' crops through the use of manures, and that the solution is in " mixed farming," a Utopian idea when dealing with " la masse paysanne, intouchable et obstinée."

In the European concerns, green manures, not necessarily leguminous, are known to be used in current practice, especially as cover in tree plantations. One must here ask, according to our correspondents, whether cover crops really do have a beneficial role in regions with a 4 to 5-month dry season. The competition for water is very severe, and the cultivated oil palms or rubber trees may well suffer.

Species used as green manure in the valley of the Niari are *Crotalaria retusa*, *C. striata*, *Pueraria phaseoloides;* cover crops include the last species and *Calopogonium mucunoides; Stizolobium deeringianum* and *Centrosema pubescens* have been abandoned. The natural flora does not appear to contain plants of potential value as cover crops. Reference is made to the leguminous species which have already disappeared from the forests due to man's activities, species of *Albizzia*, *Acacia*, *Piliostigma*, *Leucaena*, *Cassia*, etc.

Another reply from the same part of French Equatorial Africa refers to the use of *Crotalaria striata* and *C. retusa* as green manures, to the relative rates of destruction of humus in the two contrasting seasons (one dry and cloudy, the other wet with a strong sun alternating with violent rainfalls), and with the need to have a cover crop which will control *Imperata cylindrica* by shading.

In the territory of Oubangui Chari, no leguminous or other fodder is fed green or dry to the cattle; the nomadic pastoralists graze their 350,000 cattle in two regions which are favourable for this kind of husbandry and in which there is less risk of trypanosomiasis. In the dry season the pastures are burnt to promote legumes, and little success is expected from plant introduction, apart possibly from Brazil. The groundnut is an important crop and the leaves constitute an excellent forage which is fed to horses, not bovines.

As far as soil protection is concerned, legumes are used primarily in coffee plantations in Oubangui Chari, grown to prevent erosion, to furnish organic matter and so maintain the soil fertility, and to prevent the spread of noxious plants, such as *Imperata cylindrica.* The ideal plant is one which will develop rapidly without becoming rampant, which can be cut at the beginning of the dry season to form a protective mat, and which will reappear rapidly with the next rains. In addition, it should have a deep root system to avoid competing in the same soil zone as the coffee. It is considered better to spend 10 to 15 days per hectare per annum in establishing and looking after a cover crop than to spend 40 to 60 days per hectare per annum clearing the noxious weeds from the coffee plantations.

The best species for this purpose are *Leucaena glauca*, *Pueraria phaseoloides*, *Calopogonium mucunoides*, *Centrosema plumieri*, *Indigofera erecta* and *Ipomea batatas*. The sweet potato and tropical kudzu are rampant types best suited to flat or almost flat land, *Leucaena glauca* is preferred on average or steep slopes; *Indigofera erecta* can well replace *Leucaena* provided it is cut frequently to prevent it from becoming too woody. The great need is for more seed supplies of legumes.

Belgian Congo

The following notes are a synopsis of observations made at various I.N.E.A.C. (Institut national pour l'étude agronomique du Congo Belge) stations in the Belgian Congo. No mention has been made of legumes used as food e. g. peanuts, soyabeans, *Phaseolus vulgaris*, etc.

Highlands (Ituri-Kivu)

Nioka Station. To determine what legumes could be used as catch crops to counteract the noxious *Digitaria abyssinica*, experimental plantings were made of *Crotalaria agatiflora*, *Cassia didymobotrya*, *C. occidentalis* and *Sesbania*. After 2 to 3 years of flourishing growth these legumes began to decline, and Abyssinian crabgrass became established again. Lucerne is periodically attacked by rust which causes most of the leaves to fall; this effect can be avoided by cutting back every 70 to 90 days. So far this legume has given satisfactory results only on drained marshland or on irrigated soil.

Mulungu Station. *Crotalaria agatiflora* has given satisfactory results in the Kivu district as a cover crop to be planted every 2 to

3 years and has been used intensively. It can also serve as a hedge to prevent erosion and as temporary shade for young coffee.

Lubarika Station. *Calopogonium mucunoides* can be used as a catch crop immediately after a previous crop has been harvested, but unless thoroughly weeded *Pennisetum* and witchgrass (*Panicum*) will become dominant and choke out other growth. *Calopogonium mucunoides* holds its own against *Imperata cylindrica.*

Ruanda-Urundi

Rubona Station. In this very hilly and seriously deforested country, bushy legumes are of particular value. Perhaps the best is *Acacia decurrens* var. *mollis;* it grows very rapidly at high altitudes, produces good hardwood for fuel and for pitprops, and its bark is very rich in tannin. *Acacia decurrens* is used as a bushy catch crop in the Biumba territory for soil enrichment. *Acacia bracaantinga* makes excellent growth at 5,240 feet, does well on light, humid soil but not on heavy clay. *A. elata, A. pruinosa* and *A. bayleyana* are suitable for medium and high altitudes.

Albizzia spp. are useful for reforestation, for soil enrichment and as cover crops, and also yield a light wood. The chief varieties are *A. stipulata* and *A. sumatrana;* local varieties include *A. gumifera, A. grandibracteata, A. versicolor*, and *A. sassa. Cassia spectabilis* grows well at 1,600 metres, whereas *Cassia siamea* is suitable for lower altitudes. *Ceratonia siliqua* produces beans which are used for forage but above 4,600 feet its growth is uncertain, and it is attacked by collar rot.

Leucaena glauca grows well at low or medium altitudes and produces abundant fruit. It provides shade for coffee plants, can serve as a hedge to prevent erosion, and can be turned under as a green manure. *Leucaena glauca* is also a fodder for cattle and poultry. Other species, *L. buitenzorg* and *L. pulverulenta* can serve the same purpose.

Southern Border Region

Keyberg Station. Fodder Legumes. Chinese lucerne (*Medicago* sp.), developed in South Africa, produces green forage throughout the year; it requires a light, deep soil and irrigation in the winter. Blossoming is possible under cover at the end of the rainy season when there is plenty of other green vegetation. This type is used for hay, and for chopped or green forage. Two Australian varieties and a species from the south of France (*Medicago arborea*) are being tried.

Table XXVI. - Characteristics of Legumes in the Ruanda-Urundi, Belgian Congo

Genus	Species	Altitude			Forage	Green manure	Soil Crop
		low	med.	high			
Bauhinia	*picta*						
	tomentosa						
	richardsonni	x	x				x
Caesalpina	*sepiaria*						x
Calopogonium	*mucunoides*	x	x			x	x
Canavalia	*ensiformis*				x	x	x
Cassia	*tora*						
	occidentalis						
	hirsuta						
	alata						x
Centrosema	*pubescens*					x	x
	plumierii						
Clitoria	*ternatea*					x	x
	cajanifolia						
Crotalaria	*agatiflora*						
	incana						
	anagyroides						
	striata						
	r etusa						
	usaramoensis						
	juncea						
	sericea		x			x	x
Cytisus	*proliferus palmensis*						
	albus			x	x	x	x
Desmodium	*intortum*		x		x	x	x
	salicifolium			x	x	x	x
Eriosema	*montanum*						
	lejeunei						
	claessensii						
	pentaphyllum						
	shirense						
	psoraleoides						
	Humbertii						
	Jurionianum var.						
	Ituriensis						
	parviflorum						
	lebrunii						
	Tisserantii						
	cordifolium	x	x	x		x	x

Table XXVI. - Characteristics of Legumes in the Ruanda-Urundi, Belgian Congo *(concluded)*

Genus	Species	Altitude			Forage	Green manure	Soil crop
		low	med.	high			
Flemingia	sp. vel. *strobilifera lineata*	x		x		x	x
Genista	sp. vel. *scoparia*			x	x		x
Indigofera	*arrecta*						
	suffruticosa						
	endecaphylla						
	anil						
	sumatrana						
	hirsuta	x				x	
Lupinus	*luteus*		x	x	x	x	x
	roseus						
	albus						
	Cruickshanksii						
Medicago	*sativa*		x	x	x	x	x
Mucuna	*utilis* var. *capitata*	x		x	x	x	x
	artropurpurea						
Ornithopus	*sativus*			x	x		
Pachyrhizus	*bulbosus*						
	tuberosus						
Pueraria	*thunbergiana*			x	x	x	x
	javanica						
Rhynchosia	sp. *de l'Urundi*					x	x
Sesbania	*punctata*						
	aegyptiaca						
Smithia	*aeschynomenoides*			x		x	x
	Bequartii						
Tephrosia	*vogelii*						
	eriosemoides						
	candida						
	noctiflora						
	villosa						
	purpurea						
	hookeriana						
	toxicaria					x	x
Trifolium	*alexandrinum*						
	pseudostriatum		x	x	x	x	
	violaceum			x	x	x	
	incarnatum						
Vigna	*sinensis* var.	x			x	x	

Stizolobium pachylobium can be grown on stony ground during the rainy season; the whole plant is harvested and used as chopped fodder. *Pueraria thunbergiana* can be propagated only by the spreading of its underground root stock; in one year, it will cover considerable ground and yield a heavy crop of forage if irrigated during the dry season.

Legumes for Soil Cover. Crotalaria striata has abundant leafy growth but its erect habit makes it unsuitable for the prevention of soil erosion; it is, however, highly resistant to drought and is good for green manure. *Canavalia ensiformis* provides a good soil cover but is unsuitable for erosion prevention as the stalks near ground level do not branch. This variety loses its leaves both during the dry season and when its seed pods are ripening. It is useful as a quick growing green manure. *Desmodium intortum* propagates by the spreading of its underground roots and does not take root again easily. After it has become established it grows to a height of $2^1/_2$ feet and is resistant to drought.

Other local varieties include several types of *Desmodium*, particularly *D. lasiocarpum*, *Eriosema*, *Flemingia*, *Indigofera* (the climbing or the bushy variety), the large *Crotalaria* or rattlebox, *Teramnus*, *Tephrosia*, *Sphenostylis* and cowpea. The thick stands of *Rhynchosia*, particularly *R. vesinosa*, have a good root system for growth during the dry season.

Savannahs in the South-east

Gandajika Station. Until 1939, *Centrosema plumieri* was used as a cover plant, ploughed under with a disc-harrow before sowing; an average yield of 505 lb. of cotton and cottonseed per hectare was obtained, but *C. plumieri* acted as host to many insects, including some Hemiptera which attack cotton. When *Calopogonium mucunoides* is planted, average yields of cotton and cottonseed amount to 1,014 lb. per hectare. When legumes are replaced by *Manihot utilissima* and *Pennisetum purpureum*, average yields of cotton and cotton seed have increased to about 1,667 lb. per hectare.

The Lower Congo

Vuazi Station. Pueraria phaseoloides is no longer planted as its vigorous growth proved injurious to fruit trees. *Flemingia* is an ideal cover plant after the first year, when it requires constant attention.

Mayumbo

Kondo Station. Leucaena glauca can be used both for hedges on terraced hillsides and as shade for coffee; it seeds itself and may eventually choke other growth.

Equatorial Region

Food Crop Division at Yangambi. Experiments in 1937 with covers of *Pueraria phaseoloides*, *Calopogonium mucunoides*, *Crotalaria juncea*, *Cajanus indicus*, *Paspalum conjugatum* and *Pennisetum purpureum* showed that they did not maintain the fertility of the plateau soils in less than 3 years. The water table lies at a great depth beneath the soil and the cover crops are unable to develop properly. This surmise appears to be verified by the fact that better results have been obtained on land near a river where the water table is not so deep.

A preliminary evaluation of the quality of cover afforded by different species has been made, but without any evaluation for soil rehabilitation.

Category 1. Very fine cover:

(*a*) Bushy habit: *Flemingia*, *Crotalaria astragalina*.

Category 2. Fine cover:

(*a*) Bushy habit: *Sida* (KK Lumvumvu), *Cassia floribunda*, *Flemingia rhodicorfa*, *F. faginea* and *F.EV.49*, *Desmodium lasiocarpum*, *Aeschynomene indica*, *Tephrosia noctiflora*.

(*b*) Climbing habit: *Calopogonium* and *Pueraria*, *Centrosema* and *Dolichos lablab*.

Category 3. Very uneven type of cover:

(*a*) Bushy habit: *Crotalaria sericea*, *Cassia laevigata;* several types of *Desmodium*, *Indigofera erecta* and *I. suffruticosa*, *Crotalaria cetosa* and *C. goreensis*.

(*b*) Climbing habit: *Stizolobium deeringianum*, *S. aterrimum*, *Indigofera endecaphylla* and *Centrosema plumierii*.

Category 4. Cover of little value: *Crotalaria striata*, *C. usaramoensis*, *C. incana*, *C. retusa*, *C. anagyroides; Cassia tora*, *C. hirsuta*, *C. humilis*, *C. kirkii*, *C. occidentalis*, *Leucaena glauca*.

Sudan

As information supplied by officers of the Department of Agriculture has been fully used elsewhere in this publication, a detailed account of the use of legumes in the Sudan is unnecessary at this point.

Kenya

Work on the introduction of legumes into pastures more or less on the traditional British method, legumes and grasses growing together in the same ley or association, is very much at the beginning. The first stage has been the collection and preliminary testing of indigenous legumes in small plots. Kenya is rich in legumes, but species which have actually been incorporated in pastures are very few (D. C. Edwards and A. V. Bogdan, 1951).

D. C. Edwards experimented with some promising species at Kabete over a period of years. Kabete is on the fringe of the ecological zone called by Edwards " Highland Grassland and Forest Zone ;" in this favourable area, sown pastures are readily invaded by the indigenous *Trifolium semi-pilosum.* Here the problem is not to find a legume, but to find a more productive type which will persist in competition with the local clover. Edwards found that only lucerne and *Glycine javanica* persisted when sown with Rhodes grass, and subjected to periodical clipping for 3 years.

Edwards bred a local strain of lucerne called " 37 S. 4; " although the crop is already grown to some extent in the Highlands in mixture with grasses, it is only moderately satisfactory; there appears to be a need to test a wider range of strains.

In the ecological zone " Scattered Tree Grasslands " (low tree/high grass), the only legume actually used on a grazing scale is *Alysicarpus glumaceus;* critical data on its contribution to the productivity of the sward are lacking. An unidentified species of *Dolichos* (*ex* Kilima Kiu) is promising. Sown in pure stand, it has persisted quite well under grazing for 2 years; in-calf heifers have been fed on it plus Rhodes grass hay over considerable periods with satisfactory results. It is vigorous and markedly drought-resistant, continuing to grow well into the dry season.

L. R. N. Strange and A. V. Bogdan are testing the species listed below at the Scott Agricultural Laboratories, on the western outskirts of Nairobi at an altitude of 5,700 ft. The mean rainfall is 37.15 inches per year, the range during the trial years 1948-51 being from 22.16 to 55.0 inches. The nursery is in an area which

in the not so remote past was apparently covered with forest, probably of a rather dry type, with *Brachylaena hutschinsii* dominant in the upper layer. This type is characteristic of the Karura forest on the northern outskirts of Nairobi. The soil in the nursery is a deep red loam; the area was formerly under continuous cultivation of annual crops such as potatoes and maize. All the legume plots were planted with untreated seed; some promising species which showed poor germination were replanted with scarified seed, and they gave at least 80 per cent. better germination. There was no difficulty in obtaining enough seedlings of the main promising species, but it proved to be more difficult to grow these on to the adult stage. Although planted during the rainy season with a long period of rains following the planting, the seedlings in many cases died with the onset of dry weather.

It is impossible to give with each of these indigenous legumes the notes which have been supplied on their behaviour in the trial plots. Some of the names are provisional until the correct name has been determined in the Herbarium of the Royal Botanic Gardens, Kew, England.

Alysicarpus glumaceus	*Lupinus princei*
Argyrolobium leucophyllum	*Pseudarthria hookeri*
Astragalus abyssinicus	*Rhynchosia chrysadenia*
Clitoria ternatea	*Rhynchosia cyanosperma*
Crotalaria incana	*Rhynchosia elegans*
Crotalaria intermedia	*Rhynchosia menonia*
Crotalaria lotiformia	*Rhynchosia minima*
Crotalaria mauensis	*Rhynchosia usambarensis*
Crotalaria pycnostachya	*Rhynchosia* sp.
Crotalaria vallicola	*Stylosanthes bojeri*
Crotalaria sp.	*Tephrosia hildebrandtii*
Dolichos falcatus	*Tephrosia subtriflora*
Glycine javanica	*Teramnus labialis*
Indigofera brevicalyx	*Trifolium rueppellianum*
Indigofera endecaphylla	*Trifolium simense*
Indigofera hirsuta	*Vicia paucifolia*
Indigofera subulata	*Vigna reticulata*
Indigofera sp.	*Vigna vexillata*
Indigofera tettensis	*Vigna* sp.

L. R. N. Strange presented to the Sixth International Grassland Congress, August, 1952, a report of two seasons' work at Kitale (1° N. of Equator, altitude 6,000 ft., rainfall 45 inches, falling mainly between April and October, with drought period from December to March, average day temperature 81° F. in hot season, 74° F. in rains; soil a friable sandy loam of medium fertility, varying from grey to red, with pH generally between 5 and 6). The two main

temporary ley grasses with which legumes have to grow in association are *Chloris gayana* and *Melinis minutiflora*.

The functions of a legume in a ley are defined:

(*a*) complete ground cover during the life of the ley;
(*b*) effective fixation of atmospheric nitrogen;
(*c*) soil renovation through root action;
(*d*) heavy yield of palatable herbage.

Present indications are that suitable combinations for use in temporary leys, which will give both grazing and fodder for conservation, may be found among the following species which have been grouped to facilitate clearer evaluation:

1. Ground cover creepers

Low creeping, free-rooting perennials, which provide a close all-season ground cover and give " bottom " to the sward, nodulate freely, give fair yield of palatable material, and seed freely.

Vigna gracilis	*Teramnus labialis*
Teramnus repens	*Trifolium cheranganiensis*

2. Ground cover/bulk producing non-creepers

Decumbent or semi-prostrate, drought resistant perennials with clumpy growth form, generally deeper root systems than Group 1, giving fair ground cover, good bulk of fodder, seeding freely, and easy to harvest.

Stylosanthes gracilis	*Tephrosia holstii*
Alysicarpus glumaceus	*Tephrosia linearis*
Indigofera endecaphylla	*Argyrolobium*
Indigofera subulata	

3. Bulk-producing creepers

Vigorous perennial creepers, some giving considerable bulk of herbage with varying degree of rooting from nodes and stems, generally possessing a strong but not necessarily deep root system.

Vigna sp.	*Dolichos* sp. ex. Kitale
Vigna vexillata	*Dolichos* sp. ex. Kilima Kiu
Glycine javanica	*Rhynchosia elegans*
Dolichos falcatus	*Rhynchosia usambarensis*

4. Bulk-producing non-creepers

Vigorous, erect, clumpy perennials, giving high yields for conservation, and contributing comparatively little towards ground cover.

Medicago sativa

5. Special fodder conservation leys

The required growth habit would either be erect-clumpy, capable of blending with tall productive grasses, or the creeper. It is difficult to find an erect non-creeping form which will grow to the necessary height without becoming woody at the base. Selection may be necessary among the plants in Group 3.

6. Rapid-growing free-seeding plants for catch cropping

Crotalaria intermedia	*Ornithopus sativus*
Dolichos lablab	*Trifolium incarnatum*
Lespedeza striata	*Trifolium subterraneum*
Melilotus alba	*Trifolium semipilosum*
Medicago hispida var. *confinis*	*Vigna catjang*
Medicago tribuloides	*Vigna oblongifolia*

7. Perennials for special purpose dry-season (winter) grazing

Suitable species may be found among those in Group 3.

8. Soil conservation legumes for gulley stabilization, or planting as semi-permanent cover on exhausted arable land

Palatability may here be undesirable.

9. Legumes for undersowing in growing wheat or maize to give ground cover and stubble grazing during the dry season

Species in Groups 1 and 2 will generally be suitable under wheat, oats or barley, Groups 3 and 4 under maize and sorghum.

10. Legumes for surface seeding in permanent veld grassland

Uganda

Grass is regarded as the principal forage, only leguminous crop residues, such as groundnut crops, being used as forage to a limited extent on experimental farms. It would be desirable to include legumes as an ingredient of the grass ley established after varying periods of arable cropping. Such land is allowed to revert to natural grass or is sown with *Chloris gayana*, and a pasture legume would add greatly to its feed value. No legume suitable for such a purpose is known, apart from some clovers at altitudes above 6,000 feet.

In African farming practice, neither green manures nor cover crops are used, these being confined to the experimental farms of the Department of Agriculture and to a few non-native estates. *Crotalaria juncea* is used to an appreciable extent and *Cajanus cajan* less widely. *Centrosema pubescens* and *Leucaena glauca* are used as covers in permanent crops such as coffee. There is lack of evidence of the value of legumes under local conditions, and the native couch, *Digitaria scaliarum*, makes it difficult to establish a clean cover in permanent crops.

Full detail of the agronomy and testing of legumes for these purposes will be found in *Agriculture in Uganda* (*see* Tothill 1940).

Legumes at Kachwakano Experimental Farm. This farm in the Kigezi district has an altitude range of 6,400 to 7,400 feet and a mean annual rainfall of 35 inches, spread over two rainy seasons. Temperatures vary from an absolute minimum of 41° F to an absolute maximum of 82° F.

The New Zealand strain of *Trifolium repens*, imported from South Africa, has grown well in pure stands or in mixtures with *Bromus ciliatus*, *Chloris gayana*, *Pennisetum clandestinum* and *Phalaris tuberosa*. In leys with an average soil cover of 92 per cent., the clover gives about 30 per cent. cover. The cattle had to become accustomed to the clover. The seed rate was 15 lb. per acre for pure sowings and 1 1/2 lb. per acre with the grasses. The Aberystwyth strains, S100 and S184, have grown well but do not flower, nor does ladino from England or the United States; Louisiana white makes excellent growth, and flowers and seeds profusely.

Louisiana red clover (*Trifolium pratense*) becomes quickly established, produces an excellent cover and does better on poor soil than wild white. It remains green during the dry season producing good fodder and grazing when this is scarce. It can be grown successfully with the grasses noted above.

Two local clovers, *T. pseudostriatum* and *T. usambarensis* occur sporadically in local pastures; they do not persist in a pure stand and do not produce much grazing. *T. purseglovei* grows under acid swampy conditions and may succeed in planted swamp pastures.

Zanzibar

Only government stations and plantations grow legumes for forage or green manure. The local people may plant cowpeas and *Cicer arietinum* in rotation with rice, and turn under the residues. The planting of legumes is limited by the fact that sweet potatoes yield a greater bulk of food; in addition, many rice growers camp in the plains for the rice cropping season and then return home.

The Department of Agriculture continue to advise ridging and pulse planting in the rice off-season. Tropical kudzu was recommended as a cover crop in young cloves and other permanent crops, but with little success.

Species: *Pueraria phaseoloides, Centrosema pubescens, C. plumieri, Calopogonium mucunoides, Crotalaria juncea, Vigna hosei, Gliricidia, Stizolobium,* (*see* G. E. Tidbury 1947 for rice rotation).

Nyasaland

Nearly all land under cultivation is occupied by Africans and worked with a hand hoe. No legume is planted for forage or green manure. Legumes grown pure in rotation or sown mixed with maize are *Phaseolus vulgaris, Ph. mungo, Dolichos lablab, Cajanus cajan, Vigna sinensis* and *Arachis hypogaea.*

European farming includes tea, tung or tobacco plantations and dairy farming. In tea plantations, *Tephrosia candida* is sometimes used as a nurse crop for young tea, for shade as much as for soil improvement. *Albizzia glabrescens* sometimes provides shade for mature tea and is apparently beneficial. The most successful cover for tung, *Glycine javanica,* is not so beneficial as an annual crop of soyabeans; if the cover crop competed better with grass weeds, it would perhaps have more value. *Cajanus cajan* and the velvet bean are sometimes used to restore fertility in tobacco plantations. A few dairy farms plant soyabeans for feeding green or for ensiling.

There are several reasons why legumes are not used more. The long dry season from April to November kills out all but the most drought resistant types. Legumes in the tobacco areas are alternate hosts to the eelworm. The Africans have little incentive to grow legumes as there is no visible improvement in soil or in animal growth rate commensurate with the work involved. Shifting cultivation costs nothing and is satisfactory so long as large areas of land are available. Increasing pressure on the land will eventually make the greater use of legumes for soil improvement and an increase in the carrying capacity of pastures an economic proposition.

Northern Rhodesia

The use of legumes for fodder and soil improvement in Northern Rhodesia is confined mainly to the " line-of-rail " areas between Broken Hill and Livingstone in both African and European occupied areas. In the remaining parts of the country, which are largely occupied by Africans, except for an area in Fort Jameson District, legumes are grown only as food and not for their effect on the soil. The use of legumes as fodder crops is confined to European agriculture.

On European maize farms, approximately 27 per cent. of the arable land is planted to leguminous green manure, and 13 per cent. to a legume harvested for food or fodder, but planted primarily for its soil improvement value. In native areas, the use of leguminous green manures is of very recent origin; although only a small percentage of the land is planted to this type of crop, the practice is increasing rapidly. To maintain a high fertility on maize farms, it is considered essential to plant 50 per cent. of the land with a leguminous green manure crop and most progressive maize farmers follow this practice.

On other farms, such as tobacco farms, only a small percentage of the land is planted with a green manure or with a legume for its soil improvement value. Legumes are planted as fodder mainly on dairy farms, but they constitute only a small percentage of the total acreage.

There are no economic and few climatic factors limiting the wider use of legumes. Rainfall is seasonal from November to April inclusive and varies from under 30 inches to over 50 inches per annum in different parts of the country. Certain legumes, such as cowpeas and beans (*Phaseolus* sp.), are sown for fodder in February and are at the mercy of the late rains, which not infrequently are insufficient to mature the crop.

Rotations. On maize and mixed farms, the recommended rotation is maize followed by a leguminous green manure, with variations. *Crotalaria juncea* is a common green manure. On dairy and stock farms a leguminous fodder crop is introduced into the rotation: maize/legume as green manure/maize/legume as fodder. On tobacco farms the common and best rotation is tobacco/legume for green manure, fodder or seed/maize/grass fallow for 3 or 4 years. In the native areas in the maize belt, the standard rotation is maize (with kraal manure)/leguminous green manure/maize/legume for seed. In citrus orchards, a common practice is to underplant the trees with a leguminous cover which is turned in as green manure.

Nutritive Value. The chemical composition of leguminous hays and other materials in Northern Rhodesia is shown in Table XXVII.

Table XXVII. Percentage Composition of Legumes in Northern Rhodesia

Crop	Part	Moisture	Ash	Crude protein	Ether extract	Crude fibre	Soluble carbohydrate
Crotalaria juncea ..	Hay	7.66	5.11	11.42	1.01	42.17	32.63
Stizolobium deeringianum	Hay	9.3	7.8	13.3	2.5	27.6	39.5
	Seed	10.18	3.54	26.94	6.13	3.11	50.1
	Entire pods	9.87	4.21	16.89	3.85	13.87	51.4
Vigna sinensis......	Hay	10.0	7.3	10.0	1.1	29.6	42.0
	Seed	13.9	3.4	23.4	1.8	5.9	51.6
Acacia albida	Pods	7.1	3.4	11.1	1.4	27.5	49.5
Acacia woodii	Pods	5.5	7.0	7.9	0.6	24.5	54.5
Bauhinia thonningii .	Pods	5.0	5.5	6.9	2.2	22.5	58.9

The pods of *Acacia* and *Bauhinia* are valuable as stock feed in winter months.

Lucerne is grown under irrigation, making moderate growth in all except the winter months, June and July, and giving four to eight cuts of green feed for livestock of all kinds.

Southern Rhodesia

Intensive work on legume/grass mixtures for tropical conditions is beginning, but promise is seen in the specialized types of sowings already tested by Dr. J. W. Rowland in South Africa, namely, grasses such as Napier, *Setaria* or *Panicum maximum* in wide rows between which are sown annual or perennial legumes, such as kudzu, *Glycine javanica*, cowpeas, *Melilotus*, *Desmodium*, *Stylosanthes* and *Indigofera*.

Promising pasture mixtures include oats/vetches, lucerne/Rhodes grass, *Paspalum dilatatum*/wild white clover, *Phalaris tuberosa*/red clover, Napier grass/ *Glycine javanica*, and berseem sown alone.

South Africa

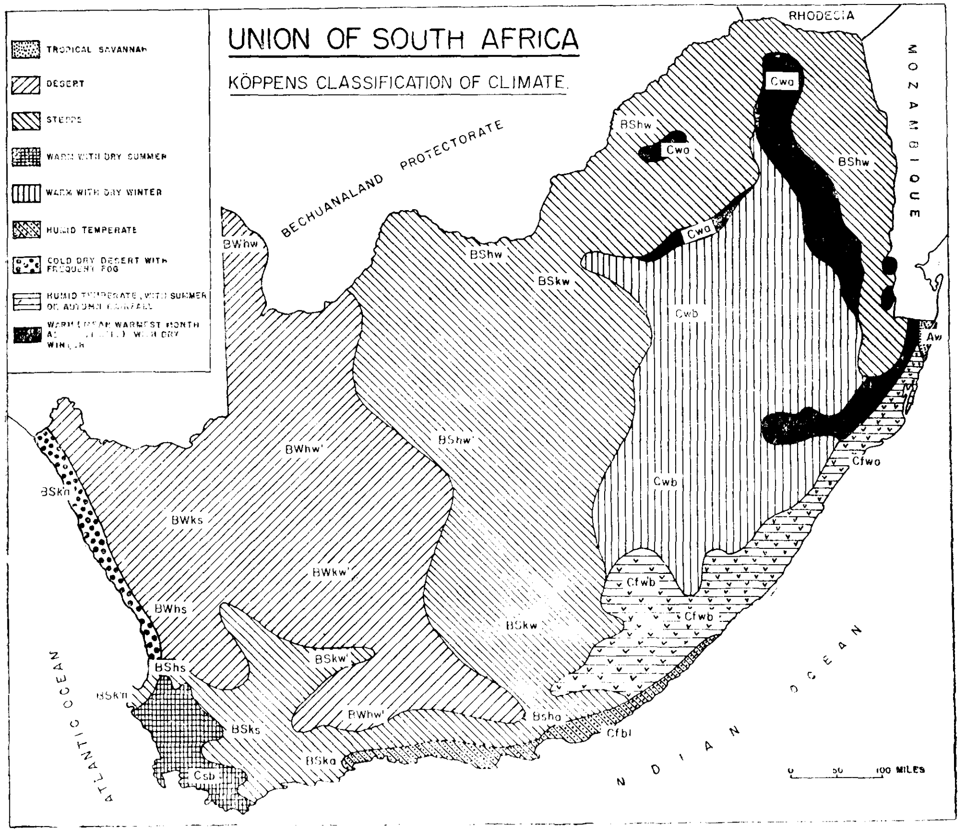
Throughout this publication we have avoided giving a precise geographical or ecological definition of tropical and sub-tropical environments. We have, in this chapter, tended to include those territories which grow the same types of crops rather than to relate our scope to any definite degree of latitude or similar limit. South Africa is borderline in this respect, as the legumes grown are characteristic of tropical, sub-tropical, temperate and winter rainfall (Mediterranean) environments.

Without some knowledge of the main climatic and other features involved, it is difficult to appreciate the place and role of any legume in a country with such variable topography, soils, altitude, climate and farming systems. A classification of climates using Köppen's system (after B. R. Schulze) is shown in on the map overleaf. The farming systems have been described in the bulletins of the Union of South Africa Department of Agriculture: 270, 275, 289, 309, 320.

In the climatic map, rainfall is pictured only in its broadest features; it increases gradually from a few inches on the west coast to about 35 to 45 inches on the eastern seaboard; the greater part of the sub-continent has a summer rainfall, the extreme south-western corner and a very narrow coastal strip on the west a winter precipitation, while the southernmost coastal area between the Outeniqua Mountains and the ocean has rainfall throughout the year.

Agricultural policy has stimulated an increasing interest in legumes for edible oil, soil improvement, pasturage, fodder and the production of protein-rich oilcake. Yet legumes have not come to occupy the place they deserve in crop rotations. Those grown most extensively are lucerne, groundnuts, cowpeas, field beans and peas. Soyabeans, lupins and the true clovers are assuming prominence, as also are vetches, sunn hemp, velvet beans, *Glycine javanica* and *Ornithopus sativus*. Apart from groundnuts and sunn hemp, the culture of legumes is often seriously affected by the eelworm (*Heterodera marioni*), and in certain areas the plant parasite, *Alectra vogelii*, may cause appreciable damage, particularly to cowpeas and groundnuts.

Cultivated Legumes. Lucerne is grown extensively for hay, but is little used for grazing because of danger of bloat. Large-scale production is confined to irrigation settlements, where as a cash crop it plays an important part in crop rotations and the maintenance of soil fertility. In the Transvaal, Orange Free State and eastern Cape Province, where lucerne is already grown under irrigation, it promises to become an important dryland pasture and hay crop on productive soils if the seeding rate is low and phosphatic fertilizer and lime



Key

A Tropical rain climates; coldest month has a mean temperature over 64.4° F.

B Arid climates; graphically distinguished from BW and C according to average annual precipitation in inches and mean annual temperature in °F.

C Warm temperate rainy climates; at least one month with mean temperature below 64.4°F. and at least eight months with mean temperature above 33.9°F.; coldest month above 26.6°F.

S Steppe.

W Desert.

a Mean temperature of warmest month over 71.6°F.

b Mean temperature of warmest month below 71.6°F.

h Hot and dry; mean annual temperature exceeds 64.4°F.

k Cold and dry; mean annual temperature below 64.4°F., but hottest month exceeds 64.4°F.

k' Cold, dry; mean annual temperature below 64.4°F., but hottest month below 64.4°F.

f Sufficient rain during all months; for summer rainfall f denotes that the precipitation during the driest month exceeds onetenth that of the wettest month; for winter rainfall precipitation of driest month exceeds one-third of wettest month.

s Dry season in summer) if appearing after f, signify seasons

w Dry season in winter) of least precipitation.

w' Same as w except that height of rainy season occurs in autumn (March-April).

n Frequent fog.

l Luke-warm; mean temperatures of all months between 50.0°F. and 71.6°F.

are applied, the latter to acid soils. In Natal and East Griqualand, it is considered that if better adapted and more disease-resistant strains could be developed, there should be more scope than at present. This is possibly also true of the high rainfall, warmer sections of the eastern Transvaal.

In the winter rainfall area (south-western Cape Province) where winter cereals have been cultivated continuously for many generations, lucerne was the first perennial legume – and non-cereal crop for that matter with which a fair amount of success was attained. It can be used only in the more favourable parts (with about 20 inches rainfall and upwards), both for grazing and as a soil renovating crop. For the latter purpose it occupies the land for 4 years. From 5 to 10 or more sheep can be carried per acre per season. Establishment is not easy owing to the dry, hot summer months and severe weed infestations. Lime is usually necessary and the seeding rate is 15 to 20 lb. per acre (Stellenbosch-Elsenburg College of Agriculture). Lucerne for 4 years followed by wheat gave a 40 per cent. higher wheat yield as compared with wheat in a wheat/fallow rotation, but the risk of " take-all " is too great and farmers prefer to use it for grazing.

Work at the Dohne Research Station (Stutterheim District, Eastern Cape Province) has recently shown the great possibilities of this crop on drylands in this area. Weed (grass) encroachment on lucerne lands is closely associated with soil acidity. Phosphatic fertilizers seem essential for success. Lucerne in 3 ft. rows can give grazing when a broadcast stand is dormant because of low soil moisture reserves.

The variety grown is the so-called South African " Provence ", which is well adapted to local conditions. Seed of this type is often exported to Australia, Argentina, California and Italy. Strains from Europe and the cooler parts of the United States persist for only about 2 years. Most of the seed is produced in the districts of Oudtshoorn, Calitzdorp and Ladysmith (Cape Province).

Under dryland and irrigated conditions, groundnuts have assumed considerable importance for their nuts, edible oil, oil cake and hay. Production has increased from 8,000 tons before the last war to between 60,000 and 70,000 tons, stimulated mainly by pre-planting price incentives aided by proper guidance and a seed loan scheme.

The crop is popular because of its drought resistance, immunity to eelworm and the good hay yields which can be obtained with good nut yields. The hay cures readily under conditions unfavourable for most hay crops and its leaves are retained well. When the soil is moist, the nut crop can be lifted by a plough, leaving the extensive root system in the soil. At the Vaalhartz Research Station it was

found that the crop exhausts the soil appreciably if roots and tops are not returned. The total digestible nutrients in well-cured hay are higher than in lucerne hay, and well dried hay is excellent for feeding to slaughter oxen and other animals.

Indigenous decumbent types of *Vigna sinensis* and *V. catjang* were cultivated long before the advent of the European, but most of the introduced varieties have done well on dryland. Though cowpeas have recently been superseded by groundnuts, they were formerly fairly common in rotation with maize for grazing or hay. The green pods are eaten as a vegetable by most native tribes, while the ripe beans are also cooked and eaten by native mine labourers. Saunder's " Upright " variety has been produced at Potchefstroom Experiment Station.

Several types of *Phaseolus multiflorus* and *Ph. vulgaris* are grown on a field scale in different parts during the summer. The large white kidney bean (*Ph. multiflorus*) is important in the cool Ermelo, Bethal and other districts of the eastern Transvaal (" highveld ") (rainfall about 30 to 25 inches). In areas receiving over 20 inches the smaller *Ph. vulgaris* is best adapted. The present trend is towards greater production of the latter for canning. Nodule production is low, and the effect on succeeding crops slight. Field beans do not yield much fodder after threshing. Many varieties are grown for the production of green beans. Extensive crops of these are grown during winter under irrigation, at altitudes below 300 ft. in parts of Transvaal and Natal where frosts do not occur.

Peas are an important irrigated winter crop; some varieties serve as a green vegetable, others are grown for canning. The crop is widespread but most of the production is under irrigation at Vaalhartz and Upington in the North-west Cape and at Lydenburg and Grobersdal in the north-east Transvaal. Since World War II, the production of peas for seed has increased so much that the Union can now meet its own requirements and export considerable quantities of certified seed. The area planted is estimated at 10,000 to 12,000 acres.

The " Green Feast " variety is the most common. The production of pea seed makes considerable quantities of hay available. As a rotation crop, peas are valued because they leave the soil free from stubble and in a good condition for cotton and other crops, whereas the trash left from wheat retards the growth of succeeding crops.

As a result of breeding initiated by A. R. Saunders at Potchefstroom in 1926, the Union now has several strains of non-shattering, yellow-seeded, high-yielding varieties of soyabeans adapted to large sections of the summer rainfall area. Widely distributed increased plantings of the "Blyvoor" variety, bred at Potchefstroom, were made over the summer of 1951/52. Soyabeans are also successful in the mist belt, where cowpeas generally fail because of attacks

of *Phyllosticta* and anthracnose. In the higher rainfall areas of Natal, the crop does well and good grain yields will be possible when suitable varieties become available from work now in progress.

Hitherto, soyabean production has been approximately 700 short tons per annum. Imported and locally produced seed are used largely for making heat-treated flour used in the diet of native mine labourers and more particularly by convalescents. The oil content is too low for profitable extraction by ordinary crushing methods which leave about 6 per cent of oil in the cake. Facilities for the solvent extraction and fractionation of vegetable oils have led to a greater demand for soyabeans.

Soyabean plants are frequently grazed or used as hay. As the leaves are readily lost, a relatively small amount of coarse fodder is obtained when the beans are threshed. It is an important hay crop, but difficult to cure.

Its indeterminate flowering habit allows seed setting to be resumed after droughts, when maize may sometimes not set seed at all. If planted after the middle of December, the growth made is somewhat reduced by the changing day-length. Inoculation is always necessary because of the general absence of the specific organism.

At the Dohne Research Station, maize may be replaced by soyabeans when grain or seed yield is concerned, but as a silage or hay crop the latter are inferior. Potash does not affect nodule formation and may be of no value or even harmful. Phosphate favoured nodule development. Apart from lupins planted in late summer, soyabeans are the best annual legume used at Dohne.

Lupins (*Lupinus albus*, *L. luteus* and *L. angustifolius*) have become very popular in the winter rainfall area (south-west Cape Province), where they are grown in rotation with the winter cereals, particularly wheat, as a soil-renovating crop and for silage; the crop is also valuable for grazing, both green and dry, or as a green manure in orchards. Lupins are proving to be very promising in this area, where it is difficult to find crops to rotate with wheat, but diseases may present difficulties later.

Red clover (*Trifolium pratense*) and white clover (*T. repens*) have been fairly widely used in Natal and elsewhere under dryland conditions where rainfall and temperature (altitude) contribute towards a fairly cool, humid climate throughout the year. They are usually grown in mixtures with grasses. More recently they have been used mixed with grasses under irrigation, for pastures throughout most of the country. Their value is largely determined by the adaptability of strains and there is room for much improvement. Alsike (*T. hybridum*) has also been employed successfully under irrigation. Subterranean clover (*T. subterraneum*) is promising as a grazing crop in the winter rainfall area and the coastal regions further east, in association with Rhodes grass in particular. Excellent

results have also been obtained at fairly high altitudes in the interior. The "Mount Barker" variety is best. Subterranean clover has suffered considerably from eelworm attacks on sandy, irrigated soils.

Strawberry clover (*T. fragiferum*) is promising under irrigation in certain parts (highveld), and its high nutritive value would justify more extensive trial. Berseem (*T. alexandrinum*) does well under irrigation in mild winters where frost is not too severe. Crimson clover (*T. incarnatum*) would appear to deserve more extensive use in the more humid "highveld" areas.

Species of *Vicia* occur as weeds in wheat in the winter rainfall area; they are, therefore, not generally used as regular crops where they might otherwise be successful. Vetches also do well in the coastal, year-round rainfall strip. In the more humid sections of the interior (high altitudes), such as in the eastern Cape Province, e. g. Maclear and Barkly East districts, the eastern Transvaal and the eastern Orange Free State, purple and more especially hairy vetch are useful for winter and spring grazing and for hay on drylands; they could be used more extensively if seeds were available and the necessary guidance given to farmers.

Sunn hemp (*Crotalaria juncea*) is the principal green manure of the irrigated lands of the summer rainfall area, ensuring considerable increases in grain yields. It is common in citrus orchards as well as in sugar cane and winter vegetable production. It is characterized by resistance to eelworm, rapid growth and the ease with which it can be ploughed under. Though palatable when grazed or made into hay, its cyanoglucoside content makes it unsuitable for continued feeding.

Velvet beans (*Stizolobium deeringianum*) are grown sporadically throughout the warm Transvaal and Natal "lowveld" for hay, grazing and green manuring, being seldom attacked by eelworm. Though capable of yielding considerable quantities of hay under more favourable conditions, distribution is determined by coolness of the climate and the length of growing season, weed competition being too severe at the lower temperatures.

Serradella (*Ornithopus sativus*) has done well as a hay and grazing crop on sandy soils along the southern coastal belt from Port Elizabeth westwards into the winter rainfall area, where soil moisture is not too low. Even at high elevations inland, such as the eastern Orange Free State and eastern Transvaal, it deserves more extensive trial.

Both the annual and biennial species of sweet clover (*Melilotus alba* and *M. officinalis*) have been used to some extent for several decades in South Africa, and undoubtedly deserve more extensive use in the more humid cool sections of the interior for soil improvement and for forage purposes.

Burr clover (*Medicago hispida*) has become fairly popular in parts of the winter rainfall area for grazing and soil improvement.

Barrel medick (*M. tribuloides*) would seem to be promising under similar conditions.

Other legumes which have been used or tried from time to time, and which are promising are *Lespedeza cuneata*, *Lotus corniculatus* and *L. uliginosus*, *Cajanus indicus*, *Pueraria thunbergiana*, *Dolichos lablab* and *Indigofera* spp.

Fodder Trees and Shrubs. Much attention is being directed to the use and improvement of *Gleditschia triacanthos*, *Ceratonia siliqua* and *Prosopis*. *Gleditschia* is doing well in the colder, humid areas, *Prosopis* in the drier western parts and *Ceratonia* where it is humid and not so cold. *Leucaena glauca* has done well under conditions prevailing at Dohne Research Station, bearing abundant pods, readily eaten by cattle and sheep. This feed causes the wool to fall out; possibly with reduced intake and combined with other feed, it may be harmless.

Indigenous Legumes. The most useful indigenous legume found is *Glycine javanica*. It has become popular in citrus orchards. Although not rapid in growth in the first year, it is nevertheless a promising legume for use with tall grasses like Napier fodder and *Setaria sphacelata*. About 3 lb. of seed per acre are used with these grasses. It is quite nutritious and palatable. It should be of considerable value in soil conservation work. It does fairly well even in frosty areas at 5,000 ft. and above.

Many species in the natural vegetation, which are valuable or useful as part of the natural grazing, are receiving attention. *Trifolium africanum* and *T. burchellianum* are the only two true clover species found in South Africa; both are widely distributed and occur under widely different soil and climatic conditions. They are palatable to stock and the value of the many ecotypes is being studied.

Dolichos gibbosus and other species of this genus are promising. Species of large genera, such as *Indigofera*, *Aspalathus* and *Lebeckia* are of considerable value and thus will be worth studying; a start has already been made. *Lotononis*, *Vigna*, *Rhynchosia*, *Psoralea* and a few other genera also contain good species.

MAURITIUS

More than 80 per cent. of the cultivated land is under sugar cane and about 92 per cent. of such land is harvested each year. A complete rotation of sugar cane extends over 6 or 7 years and when

replanting is necessary, the old stumps are often ploughed out and a new plantation made immediately. In the north of the island, the last ratoon crop is cut in November and the crop not replanted until the following May. Much of the land not under sugar cane is planted with vegetables, maize, tea and aloe fibre (*Fourcraea gigantea*).

There are fairly large areas where *Leucaena glauca* grows wild, often in association with aloe fibre; these are in the drier parts of the Island where *Albizzia lebbek* also grows well. *Stizolobium deeringianum* is grown to a limited extent in the north between two rotations of sugar cane, but it is hoped to divert part of the land to groundnuts. *Canavalia ensiformis* is sometimes planted in the interlines of the young plant crop of sugarcane, and later buried in the interlines. Very little "green dressing" is grown in tea plantations, but efforts are being made to expand the growth of *Tephrosia candida.*

Where land reaches a value of £400 sterling per acre, sugar planters wish to crop it to the maximum to reduce the cost of production. There is no evidence that any increase in crop production following a fallow under a leguminous green dressing for one year would compensate for the loss of one year's sugar crop. Only where lands lie idle for about 6 months is *Stizolobium deeringianum* planted.

About 75 per cent. of the cattle population, the milk animals, are stall fed. Suitable leguminous forage crops for the wetter and cooler uplands have not been found. The fodder value of *Leucaena glauca* and *Albizzia lebbek* is high, but the protein of the latter species is not of very high quality. The leaves and seeds of *Phaseolus lunatus* appear to be toxic to livestock. Some wild, low-yielding but palatable species of legume include *Medicago denticulata, M. lupulina, Vicia sativa* and *Melilotus indicus.*

MADAGASCAR

Legumes are rarely used as fodder, although *Dolichos lablab* and *Vigna sinensis* are beginning to be utilized on farms which have introduced improved cattle. Green manure crops are not grown to any extent, except at the Station agronomique du Lac Alaotra, where the following legumes are grown in rotation with manioc: *Stizolobium deeringianum, Dolichos lablab, Vigna sinensis, Crotalaria fulva* and *C. anagyroides.* The further utilization of legumes

is limited by difficulties in procuring or harvesting seed and by lack of irrigation for the dry season.

The manioc rotation referred to is manioc/manioc/green manure. Other possible rotations are: rice/green manure as an inter-season irrigated crop, or manioc/manioc/legume for green forage/groundnuts/ legume turned under for green manure.

The following have also given good results at the Station: *Phaseolus lunatus, Cajanus cajan,* white lupin and soyabean.

INDIA

Legumes are widely used for green manuring, as forage for cattle and to improve the fertility of the soil. Those used for green manuring include *Crotalaria juncea, Sesbania aculeata, Cyamopsis psoralioides, Phaseolus radiatus, Ph. trilobus* and shrubs such as *Gliricidia* and *Pongamia.* The common fodder legumes are *Trifolium alexandrinum, Medicago sativa, Melilotus parviflora, Trigonella foenum-graecum* and Indian "vetches" such as *Lathyrus sativus.* Kudzu has recently become popular, particularly in Assam, and is considered to be promising for certain conditions. All legumes which have been tested earlier and abandoned require to be tried again with better control of inoculation and fertilizer requirements, especially phosphate. Shortage of seeds has been a limiting factor particularly with berseem and in species such as *Sesbania aculeata,* which is so valuable in the reclamation of alkali land. The importance of bees for the pollination of berseem has now been demonstrated.

We have already referred to the practice of mixed cropping which is so characteristic of Indian cropping systems, and which has been credited with doing more than any other factor to maintain the fertility of Indian soils. Naturally, there are many types of crop rotations in India, but there is a need for experiments into various sequences and fertilizer treatments in relation to the maintenance of soil fertility and crop yields so that the vague terms "soil-exhausting" and "soil-recouping" can be better understood.

Experiments with berseem in rotation at the Indian Agricultural Research Institute may be quoted. This crop was grown in rotation with cowpeas (unmanured) for three consecutive years (1940-42). The subsequent cowpea and wheat crops were grown on the fertility

built up by berseem in conjunction with phosphate. In 1946/47, guar (*Cyamopsis psoralioides*) replaced the cowpeas as it responded better. Phosphate produced a striking increase in the yield of the berseem and in the yields of unmanured wheat following. The phosphorus and calcium content of the berseem and cowpea fodder, the phosphorus and nitrogen content of the wheat grain, were all increased. Total nitrogen of berseem and cowpea hay and wheat grain showed marked increases. In an experiment on berseem in rotation with maize and wheat, the response of the legume to ammonium phosphate was very significant, indicating the value of nitrogen in addition to phosphate.

In northern India, winter legumes which may be successful as rabi crops include *Vicia sativa*, *Medicago hispida*, *Melilotus alba* and *Lathyrus sativus*, especially where some irrigation is available.

In times of fodder scarcity in India, anything green or dry is fed to the cattle. At these times and especially in jungle areas a number of trees are lopped for fodder. Leguminous trees used in this way include *Dalbergia sissoo*, *Albizzia lebbek* and *Acacia arabica*. The chemical composition and nutritive value of tree leaves are being studied by Dr. N. D. Kehar at the Indian Veterinary Research Institute, Izatnagar.

In a discussion at the F. A. O. regional meeting on Land Utilization in Tropical Areas of Asia and the Far East, reference was made to methods of green manuring in rice fields in Madras. The relevant paragraphs are quoted:

"Experiments in Madras have shown that about 4,000 lb. of green leaves per acre in the paddy field at the time of puddling improve the yield up to 40 per cent. in the first year. There has been a difficulty in providing the green manure, as such crops had to be raised in the fallow period when there is lack of irrigation water, and cattle trespass on the land. These difficulties have been tackled in Madras by raising quick-growing leguminous shrubs like *Gliricidia maculata* on the bigger bunds and *Sesbania speciosa* in the paddy fields along the margins of the bunds. These grow to heights beyond the reach of cattle and goats within three or four months, and there is no adverse shade or root effect on the paddy crop.

"In an average paddy field, there are about 500 yards of bunds, some of which can be left without planting for use as footpaths. *Gliricidia* stands repeated lopping and supplies about 20 lb. of leaves per plant within 18 months. *Sesbania speciosa* is a very quick-growing plant with pithy stems. It is free from pests and can be grown under varied conditions. It withstands drought and resists salinity. Seedlings are raised and transplanted about six inches apart in the paddy field along the margins of the bunds when the plants are four to six weeks old. The first crop of *Sesbania* produces over 4,000 lb. of leaves, sufficient to maintain the second crop of paddy. When grown in the second crop, it provides sufficient leaves for the first crop of the next season. Each plant produces about four ounces, or over 9,000 seeds, in four to five months. A handful of seeds costs less than $^1/_{100}$ of a rupee and enables the cultivator to raise seeds for future needs and manure for the next crop equal in value to 17 rupees worth of ammonium sulphate or 30 rupees worth of groundnuts. Vigorous efforts are being made in Madras to show the value of this green manure plant, and when the practice becomes widespread there will be no problem of rice shortage in Madras. It is believed that *Sesbania speciosa* will prove to be of value in other tropical regions".

PAKISTAN

East Bengal

This province has 25.3 million acres under cultivation annually. The important crops are rice, jute and sugar cane. Legumes are grown on the rice and jute fields as a winter season catch crop in the double-cropped areas only, but this total area does not exceed one million acres. Probably 30 per cent. of the legume crop is used for forage, 5 per cent. as green manure, and the remainder harvested for human consumption. The farmer finds it economically impossible to spare a legume crop for use as forage or green manure; in any case, legumes grown in winter cannot be ploughed under because of the lack of rainfall. A good crop cannot be obtained in the absence of irrigation. Any further increase in the area under legumes is thought to be unlikely in present agricultural conditions. Perhaps some increase might be possible in certain areas if damage by stray cattle could be reduced.

The species grown are:

Crop	Acreage
Lens esculenta	267 000
Cicer arietinum	225 000
Phaseolus mungo	118 000
Phaseolus aureus	110 000
Crotalaria juncea	20 000
Lathyrus sativus	unknown
Cajanus cajan	7 000
Vigna unguiculata	small
Sesbania aculeata	small
Pisum sativum	small
Glycine max	experimental

A number of improved varieties of *Cicer*, *Lens*, *Phaseolus aureus*, *Cajanus cajan*, and *Glycine* have been developed and are being distributed to growers.

Punjab

Legumes are grown extensively for forage. About 75 per cent. of the area grown for winter fodder in irrigated tracts is under *Trifolium alexandrinum*. *Cicer arietinum* and field peas are used as fodder in rain-fed and riverain lands. Lucerne occupies a fairly large area in irrigated tracts. During summer *Phaseolus aconitifolius* and *Cyamopsis psoralioides* are sown alone or mixed with *Sor-*

ghum and *Pennisetum typhoideum*. *Cyamopsis psoralioides*, *Crotalaria juncea* and *Sesbania aculeata* are used widely for green manure. Larger farmers practise green manuring to a certain extent, but economic factors prevent others from giving it the attention it deserves. Cash crops give a better and immediate return, and expensive irrigation water cannot be spared for green manure crops.

Current rotations are: maize/berseem/cotton/sorghum/gram/cotton and senji/wheat/wheat/maize/senji/sugar cane.

Leaves and twigs of *Acacia modesta* and *A. arabica* are relished by goats and camels, and leaves of *Albizzia lebbek* are fed to cattle in periods of fodder scarcity.

Sind

With its extreme climate, temperatures down almost to freezing point in winter and up to 114° F. in summer, hot, scorching winds of the 40-day period known as the Chaliho, and an average rainfall of 5 inches, Sind is fortunate in having one of the largest irrigation systems in the world. But because of this, farmers are unwilling to sacrifice the return from cash or food crops to grow green manure legumes. Winter legumes tend to be grown more than summer legumes, some enterprising zamindars growing *Crotalaria juncea* and *Cyamopsis psoralioides*. In the area not supplied with perennial irrigation, almost the entire area is under rice in the kharif season, followed by rabi legumes grown on the residual moisture.

North-west Frontier Province

Berseem (*Trifolium alexandrinum*) and Persian clover (*T. resupinatum*) are widely grown for fodder and green manure, the last cut usually being ploughed under. Even if this is not done, the soil fertility is raised sufficiently to produce a good kharif (summer) crop of maize or paddy. Water supply is the limiting factor, and these clovers are not cultivated above 5,000 feet elevation because of rather heavy snowfalls. The clovers are grown in an irrigated rotation following kharif crops, chillies and sugar cane.

Berseem (Miscawi variety) is sown generally mixed with maize, barley or mustard, at 2 to 2 1/2 lb. per acre, in September; it gives five to seven cuts up to mid-July, yielding 30 to 40,000 lb. green fodder per acre. It is very palatable but is liable to cause tympanitis in cattle.

There are two strains of the Persian clover or shaftal, one early and one late. If planted in September at 1 to 1 1/2 lb. per acre mixed

with maize, barley or mustard, it gives 20 to 25,000 lb. green fodder per acre up to mid-June. It is more liable to cause tympanitis, and is thought to have a greater effect on soil fertility than berseem. Applications of phosphatic manures increase yield and quality. There is interest in the possibilities of a tetraploid produced by treatment with colchicine.

Bahawalpur State

The growing of legumes as green manure was unknown before the introduction of canal irrigation; recently progressive elements have adopted the practice, but only where ample water and adequate ploughing machinery are available. Green manuring is confined to wheat, cotton and sugar cane. Progressive cultivators practise the following rotations:

(*a*) Green manure/sugar cane/wheat/cotton.
(*b*) Green manure/wheat/cotton.

Where both soil improvement and forage are required:

(*c*) Berseem or any leguminous forage/cotton/wheat.
(*d*) *Cicer arietinum* or any leguminous forage/paddy or cotton.

Legumes are used extensively as forage. Species grown either for green manure, forage or grain production are *Medicago sativa*, *Trifolium alexandrinum*, *Cyamopsis psoralioides*, *Phaseolus aconitifolius*, *Melilotus alba* and *M. parviflora*, *Cicer arietinum*, *Lathyrus aphaca* and *Crotalaria juncea*.

Lucerne supplies fodder throughout the year on irrigated areas. It is sown from September to November (8 to 12 lb. per acre) on light loam, and may be kept down for 4 to 5 years. As is the case throughout Pakistan and India, lucerne fodder is considered to be especially suitable for horses; it is also fed to cattle mixed with wheat straw.

Berseem is sown each year from September to October (8 to 16 lb. per acre), grows best on loams and sandy loams, and gives four to six cuttings of green fodder per year from December to May. It is fed mixed with dry fodder to cattle, especially bullocks and milch cows, stimulating the milk production of the latter.

Acacia arabica, *A. leucophlora* and species of *Prosopis* occur in the natural vegetation, and the leaves and pods are fed to camels, sheep and goats.

The main factors limiting the wide use of legumes, especially as green manure, are scarcity of water and of rainfall, ignorance of the cultivators, lack of adequate technical staff and sufficient propaganda, under-equipment of the agriculturist, tendency to give more importance to cash and food crops, insecurity of tenure as a deterrent to improvement of land and increase in production, and the tympanic effect of legumes if fed in excessive amounts and without carbohydrate roughages.

BURMA

Grain legumes are grown for human consumption in Burma, and the crop residues are fed to cattle. No special leguminous fodders are grown. Only *Vigna sinensis*, *Phaseolus radiatus* and *Crotalaria juncea* are grown to some extent as green manure. Legumes are grown mostly in the central Burma dry zone, where rainfall is from 30 to 50 inches.

Table XXVIII. Percentage Composition of Burmese Cattle Feeds

Species	Fodder	Moisture	Ash	Crude Protein	Ether Extract	Crude Fibre	Soluble Carbohydrate
Cicer arietinum	Crushed seed	11.61	3.05	19.91	1.02	7.38	57.03
Phaseolus lunatus ...	Vines and pod husks	5.46	4.94	5.87	0.43	37.93	45.37
Cajanus cajan	Pod husks	6.29	4.43	4.92	0.43	39.14	44.79
Arachis hypogaea. ..	Cake	7.25	3.84	43.62	11.91	1.94	31.44

Other species cultivated are *Arachis hypogaea, Cajanus cajan, Pisum sativum, Cicer arietinum, Glycine max, Dolichos lablab* var. *lignosus, Phaseolus lunatus*, and *Ph. mungo.* Wild legumes include *Ph. trilobus, Rhynchosia minima, Smithia sensitiva, Lathyrus sativus* and *Melilotus alba.*

Legumes are usually grown alone, at 70 lb. per acre broadcast, 30 to 40 lb. per acre in drills and 20 lb. per acre with square sowing. The dried and crushed vines and pods after threshing and sieving out the leaves are stored separately and fed to cattle as concentrates mixed with sorghum chaff. Legumes are sometimes grown in mixtures with crops such as maize or tobacco.

A number of selected varieties of legumes have been produced in Burma and important introductions were Japanese and Spanish groundnuts.

THAILAND

Thai cattle are left to graze in the jungle or on grasses growing near the rice fields. Even rice plants are sometimes clipped for cattle feed while most hogs receive concentrates without accompanying green feed. Leaves of *Sesbania grandiflora* and *Leucaena glauca* are sometimes fed to chickens.

On the low lands, farmers grow rice and elsewhere they practise shifting cultivation: they have little interest in green manures. There are certain types of upland farming in which a short rotation is practised incorporating a crop or two of groundnuts, soyabean or *Phaseolus mungo.*

Although many tropical legumes thrive in Thailand, the farmer who grows legumes at all wishes to have types which will produce a cash crop, any soil improvement obtained being purely incidental. Crop residues of the grain legumes grown are, however, frequently returned to the field. With the wooden plough drawn by a single animal, it would be difficult to turn under a heavy green manure crop. The upland areas are cropped for one or two crops, and allowed to lie fallow for a number of years, or until the land becomes thickly covered with bushes or trees, and is relatively free of *Imperata cylindrica* and other noxious weeds. It has not yet been demonstrated which legumes, if any, might replace the bush and weed growth on the fallow.

MALAYA

Although no reply to the questionnaire of September 1951 was received from Malaya, reference should be made to the publication *Fodder and Feeding Stuff in Malaya*, by Sunn Lay Teik (Dept. Agric. Scientific Services, No. 24, 1951, pp. 88). This contains comments on the usual tropical leguminous fodders, and instructions as to how they may be used in rations for different types of livestock. It also contains three extensive and valuable tables, dealing respectively with composition and nutritive values, mineral matter, and vitamins. Extracts from the first are given in Table XXIX. insofar as they refer to leguminous fodders.

Table XXIX. Composition and Nutritive Values of Malayan Leguminous Feeding Stuffs (after Teik, 1951)

Feeding Stuff	Chemical Analysis						Calculated Digestible Nutrients				Dry Matter	Calculated from Digestible Nutrients	
	Water %	Protein %	Fat %	Carbohydrates Soluble %	Carbohydrates Fibre %	Ash %	Protein %	Fat %	Carbohydrates Soluble %	Carbohydrates Fibre %	%	Nutritive ratio	Starch equivalent
Green Fodders													
Albizzia falcata, young twigs	69.2	7.4	0.8	18.0	2.9	1.7	4.1	0.2	8.5	0.6	30.8	2.3	13.3
Albizzia odoratissima, young twigs	64.6	7.9	0.8	20.6	4.8	1.3	4.4	0.2	9.7	1.0	35.4	2.5	15.2
Alysicarpus vaginalis, green shoots	72.0	3.9	0.7	13.8	6.0	3.6	2.2	0.2	6.5	1.3	28.0	3.8	10.3
Calopogonium mucunoides, leaves and stems	74.3	4.0	0.6	11.4	8.1	1.6	3.0	0.4	9.2	4.9	25.7	5.0	17.7
Cassia siamea, young twigs	66.1	6.8	1.9	17.8	5.6	1.8	3.8	0.4	8.4	1.2	33.9	2.8	13.9
Centrosema pubescens, leaves and stems	75.7	5.4	0.6	8.5	7.5	2.3	4.1	0.4	6.9	4.5	24.3	3.0	16.0
Clover, Persian (*Trifolium resupinatum*)	79.0	3.4	0.3	9.7	5.7	1.9	2.2	0.2	6.9	3.0	21.0	4.7	12.4
Cowpea (*Vigna sinensis*) vines	88.9	3.4	0.2	3.2	2.7	1.6	2.6	0.1	2.6	1.6	11.1	1.7	6.8
Desmodium heterophyllum, leaves and stems	75.0	2.5	0.4	14.0	7.6	3.5	1.9	0.2	11.3	5.3	25.0	9.0	18.8
Desmodium ovalifolium, leaves and stems	76.0	2.2	0.5	9.5	9.6	2.2	1.7	0.3	7.7	5.8	24.0	8.3	15.7
Desmodium triflorum, leaves and stems	75.0	2.2	0.7	12.6	7.3	2.2	1.7	0.4	10.2	4.4	25.0	9.1	17.0
Dolichos lablab, leaves and stems	81.6	5.8	0.9	6.9	2.5	2.3	4.2	0.6	5.0	1.3	18.4	1.8	11.4
Enterolobium cyclocarpum, young twigs	56.5	7.3	2.3	26.4	5.3	2.2	4.1	0.5	12.4	1.1	43.5	3.6	18.3
Pithecellobium saman, young twigs	61.1	9.6	1.1	17.9	8.6	1.7	5.4	0.3	8.4	1.8	38.9	2.0	15.9
Four-angled bean (*Psophocarpus tetragonolobus*)	78.9	6.3	1.0	7.9	4.1	1.8	4.8	0.6	6.4	2.5	21.1	2.1	14.6
Gliricidia maculata, young twigs	72.9	5.1	1.0	15.1	4.2	1.7	2.9	0.2	7.1	0.9	27.1	2.9	11.1
Groundnut (*Arachis hypogaea*) leaves and stems	73.1	4.7	0.6	13.9	5.4	2.3	3.1	0.3	10.7	2.7	26.9	4.5	16.9
Horse gram (*Dolichos biflorus*), leaves and stems	81.8	3.2	0.4	9.4	3.9	1.3	2.4	0.2	7.6	2.3	18.2	4.3	12.5
Indigofera endecaphylla, leaves and stems	80.5	4.1	0.6	7.9	4.7	2.2	3.1	0.4	6.4	2.8	19.5	3.3	12.9
Leucaena glauca, young twigs	68.4	8.8	1.0	17.4	3.3	1.1	4.9	0.12	8.2	0.7	31.6	1.9	13.6
Leucaena glauca, old twigs	61.8	9.1	1.8	20.0	4.8	2.5	5.1	0.4	9.4	1.1	38.2	2.2	16.1
Stizolobium deeringianum, leaves and stems	83.4	5.8	0.5	6.4	2.4	1.5	4.4	0.3	5.2	1.4	16.6	1.7	11.3
Pigeon pea (*Cajanus cajan*) leaves and stems	67.7	4.2	1.1	18.9	7.0	1.1	2.9	0.8	14.7	3.5	32.3	6.9	22.5
Pueraria phaseoloides leaves and stems	80.9	3.8	0.4	7.9	5.5	1.5	2.9	0.2	6.5	3.3	19.1	3.5	12.9
Red bean (*Phaseolus calcaratus*), whole plants at flowering	68.0	5.4	0.6	13.7	9.8	2.5	3.9	0.4	9.9	4.9	32.0	4.0	19.3
Stylosanthes gracilis, two months old cuttings	76.0	4.0	0.4	9.6	7.6	2.4	2.3	0.1	4.5	1.6	24.0	2.8	9.0
Concentrates, Seeds													
(*a*) grains and oil													
Dolichos lablab, beans, unripe	81.3	4.3	0.5	10.0	2.6	1.3	3.3	0.3	8.1	1.6	18.7	3.1	13.4
Dolichos lablab, seeds, ripe	48.1	13.6	0.9	32.6	2.3	2.5	9.0	0.6	30.3	1.3	51.9	3.7	41.3
Gram, Bengal (*Cicer arietinum*)	11.1	22.9	3.5	50.3	9.0	3.2	15.1	2.2	46.8	5.1	88.9	3.8	70.8
Gram, Black (*Phaseolus* sp.)	7.4	24.3	0.6	59.5	4.9	3.3	16.0	0.4	55.3	2.8	92.6	3.7	74.0
Gram, Green (*Phaseolus aureus*)	11.9	21.5	0.9	57.9	4.5	3.3	14.2	0.6	53.8	2.6	88.1	4.1	71.0
Groundnut (*Arachis hypogaea*), decorticated	7.3	30.8	44.3	13.6	1.6	2.4	27.7	39.9	11.4	0.1	92.7	3.7	133.7
Pigeon pea (*Cajanus cajan*)	11.0	20.8	0.8	54.2	9.4	3.8	17.9	0.5	50.4	4.3	89.0	3.1	72.7
Red bean (*Phaseolus calcaratus*)	18.7	18.9	0.5	53.3	4.9	3.7	16.4	0.4	48.5	2.8	81.3	3.2	67.6
Soyabean (*Glycine max.*)	11.5	38.5	16.4	24.1	4.9	4.6	34.3	14.4	16.1	1.8	88.5	1.5	84.8
(*b*) by-products													
Groundnut cake, decorticated	7.8	47.9	10.9	25.0	3.6	4.8	43.1	9.9	21.3	1.3	92.2	1.1	87.0
Soyabean cake	15.2	40.3	5.4	29.6	4.3	5.2	34.3	4.6	29.0	2.9	84.8	1.2	75.2
Soyabean refuse, fresh	85.9	5.5	0.7	5.8	1.6	0.5	4.7	0.6	5.7	1.1	14.1	1.7	12.7

VIET-NAM

The perennial industrial crops – rubber, tea and coffee – predominate and only the large landowners have the financial and technical means to experiment with legumes and risk failures. Legumes, if grown at all, are not for feeding but for green manure, cover, and erosion prevention.

Indigenous farming is concentrated in the alluvial over-populated deltas of the Red and Mekong rivers. Holdings are extremely fragmented particularly in northern and central Viet-Nam, and rice cultivation is the traditional type of farming. Even where small areas are not under rice, other food crops are planted because of the immediate pressure of hunger. In addition, the influence of advisory services has been confined to a few growers with the means and the training to carry out the recommendations.

In the rice areas, the crop is grown in the age-old way through intensive cultivation using farmyard or other manure of organic origin. If legumes are grown, they are primarily for grain and only incidentally are their residues turned under.

In the uplands of northern Viet-Nam, however, velvet bean is grown alternately with rice and ploughed under. In the plain to the north, *Crotalaria striata* is preferred.

In the tea, coffee, rubber and tung plantations, legumes are intercropped with the main crops for green manure, or used along borders of gardens on slopes to prevent erosion, or planted for shade trees, wind-breaks, or cover crops. A rotation of green manure crops is generally followed, e.g., *Crotalaria striata*, *Tephrosia candida*, and *Calopogonium mucunoides*. The legumes used are adjusted to the age of the plantations, erect plants for the first few years in coffee, and later creepers.

Species for cover and green manure in southern Viet-Nam: *Acacia dealbata*, *Cajanus cajan*, *Calopogonium mucunoides*, *Centrosema pubescens*, *C. plumieri*, *Crotalaria anagyroides*, *C. alata*, *C. usaramoensis*, *C. striata*, *Desmodium ovalifolium*, *Dolichos lablab*, *Erythrina lithosperma*, *Indigofera endecaphylla*, *I. hirsuta*, *Mimosa invisa*, *Phaseolus semi-erectus*, *Pueraria phaseoloides*, *Tephrosia candida*, *T. vogelii*, *Vigna hosei*.

The report from the Bencat Station in southern Viet-Nam enumerates desirable qualities in a green manure crop: (*a*) ability to cover soil thoroughly, (*b*) resistance to encroachment by weeds, and (*c*) high yield of green matter with high nitrogen content; and for cover crops the additional qualification of ability to stand drought. In order for a green manure plant to be used on a large scale economically, it must produce abundant seed and the seed must be readily harvested. The principle accepted is that a legume cannot be used for green manure or cover unless it seeds so plentifully that the area to be set aside for seed production is a maximum of 2 per cent. of the total area under this crop.

AUSTRALIA

Queensland

Tropical Queensland extends between Longitude 138° E. and 151° E. and northward from Latitude 23 ½° S, and comprises four distinct climatic zones, distinguished by characteristic vegetation:

A. The coastal plains of eastern tropical Queensland with well-distributed rainfall of from 60 to nearly 200 inches per year, accompanied by mild winters, with summers of high humidity and moderately high temperatures rarely exceeding 100° F. in the shade.

B. The coastal uplands of about 2,000 to 3,000 ft. elevation, such as the Eungella Range (Lat. 21°) and the Atherton Tableland (Lat. 17°) with rainfall of from 50 to 100 inches per year. These regions experience cold winters and some winter rainfall which makes the growing of white clover possible.

C. The country bordering the Gulf of Carpentaria i. e. north of approximately Lat. 21° S. and extending to the Cape York Peninsula. This area has a definite monsoonal climate, with a 20 to 40 inch rainfall depending on location. The wet season usually occurs during the summer months, December, January, February and early March. The remainder of the year is normally dry. Frosts occur only on the higher portions.

D. The arid to semi-arid plains country of western Queensland. The rainfall, normally confined to the summer, ranges from 14 to 15 inches to under 6 inches per year. Diurnal variations in temperature are high, and severe winter frosts are experienced. Maximum summer temperatures often exceed 100° F. and humidity is low.

Legumes are cultivated on a commercial scale as distinct from the experimental only in zones A and B and the eastern and south-eastern sections of zone C.

In zone A of the coastal plains, the major primary industry is sugar cane culture and legumes are used extensively as green manure. Their use as fodder is negligible, as most cane farms are highly mechanized. It is estimated that 60 per cent. of sugar cane farmers incorporate green manures in their system of cane culture. The chief limiting factor at present is lack of seed with a resultant steep rise in price, Poona peas (*Vigna sinensis*) selling (February 1952) at 78s. (Aust.) per bushel. The use of certain perennial grazing legumes is limited to experimental plots with one or two small areas established for commercial trial.

PLATE 13. Cultivation of lucerne in wide rows in Queensland to facilitate weed control under sub-tropical conditions. (Photo by T. B. Paltridge)

In zone B, white clover (*Trifolium repens*) is used widely in the *Paspalum dilatatum* and *Pennisetum clandestinum* pastures. Lucerne is used to a small extent, the acreage being limited by the difficulty of curing hay in this climate. Groundnuts are grown in the lower rainfall belt of the Atherton Tableland, and their use in a crop rotation with maize – the staple crop – would help to build soil fertility. The common green manures, while expected to be of value for the soil, have not been accepted into the normal cropping programme.

In the eastern monsoon country of zone C the introduced legume *Stylosanthes sundaica* (Townsville lucerne) is spreading rapidly, particularly on the poorer, less heavily grassed areas. Its ability to colonize on open areas and its occurrence on Garbutt airfield at Townsville (in a drier zone of the tropical coast) have resulted in its appearance on many north Queensland aerodromes. Its hooked

fruit greatly facilitates its fortuitous spread. Its potential value as fodder in the cattle-raising country of this zone is considerable. Demand for seed of this species is keen and it should play an important part in the livestock industry of this zone in the future.

In the south-east corner of zone C, the Mareeba Dimbulah district north-east of Cairns is an important seed-producing centre for the green manure crops of the sugar producing country. Here legumes, such as cowpea and velvet bean, are grown in pure stands or in conjunction with maize in the case of velvet beans, when the maize acts as a temporary trellis. Pure stands of the suitable varieties are harvested mechanically.

In the arid zone D cultivated legumes are of no importance.

As already mentioned, the main factors limiting the wider use of green manure legumes in the sugar industry of the tropical coast are shortage of seed and the resultant high prices. Other factors are the reluctance of some growers to accept the existing evidence of the value of these legume crops, and in some areas where irrigation is used, the impossibility of growing the green manure crop without watering.

On the Atherton Tableland, the restricted use of green manures in the maize growing industry may be said to be due to economic factors. The maize growers in the main are not yet convinced that their arable land is sufficiently extensive to justify losing a season's maize crop by growing a green manure, despite experimental evidence of its value. The use of a legume cash crop, such as groundnuts, in which the stubble is ploughed under seems to offer a compromise in the drier zones of the maize belt where the crop can be cured in the field.

The suitability of sown legumes as fodder crops in the cattle grazing country of zones C and D is not yet proved. Reasons are economic and climatic. Holdings are large, with areas of up to 3,000 square miles, and costs of machinery and cultivation are high. Rainfall is very seasonal, and land preparation and sowing during the wet season are extremely difficult. Experiments are in progress; it may be possible in certain favoured areas in these two zones to use grain sorghums, which are more drought-resistant than the forage legumes. A notable exception is the rather fibrous annual, *Stylosanthes sundaica*, which can be expected to improve the poorer sandy country of parts of zone C in Cape York Peninsula and adjoining areas. Costs of seed and of distribution over large areas prevent its more widespread use. Natural spread seems certain.

Existing practices may therefore be summarised as follows:

(*a*) legumes are used on 60 per cent. of sugar cane farms as a green manure crop, but very little grazing is carried out as stock numbers, whether cattle or horses, are negligible.

(*b*) white clover is an important pasture legume of the paspalum and kikuyu pastures of tropical tablelands.

(*c*) lucerne has limited value as hay owing to climatic difficulties of curing

(*d*) cowpeas and velvet beans are used to a limited extent only as green manure in the maize districts of the Atherton Tableland

(*e*) peanuts are being used as part of a crop rotation in the drier zones of the maize belt

(*f*) *Stylosanthes sundaica* is spreading through the sandier belts of the eastern monsoon zone

(*g*) legumes are used to a limited extent as green manures and cover crops in the horticultural industry.

Systems of improved land usage should include:

(*i*) use of tropical pasture legumes (discussed below) with suitable grasses on land not assigned to sugar in zone A for fattening of young steers brought in from the breeding country of climatic zone C;

(*ii*) extension of areas under lucerne/Rhodes grass mixtures on the Atherton Tableland with increased attention to dairying or fattening in the main maize-growing district;

(*iii*) incorporation of a green manure/maize rotation, or increased use of the ground nut/maize rotation in the maize areas of the Atherton Tableland;

(*iv*) growing of lucerne under irrigation in small favoured areas in zones C and D;

(*v*) use of legumes as green manure and cover crops in banana plantations and other horticultural activities.

Species used or being tested. Cowpea (*Vigna sinensis*) varieties: Poona pea, Reeves, Giant or Mammoth, Groit, Cristando, Victor. Velvet beans (*Stizolobium* spp.) varieties: White Mauritius, Black Mauritius, Somerset, Marbilee, Smith Jubilack. *Stylosanthes gracilis, S. sundaica, Pueraria phaseoloides, P. thunbergiana, Centrosema pubescens, Calopogonium mucunoides, Crotalaria goreensis, C. usaramoensis, Trifolium repens, Arachis hypogaea, Medicago sativa* (Hunter River).

Experiments have been concentrated on pasture legumes in the following associations: *Centrosema pubescens/Panicum maximum* (purple topped), *Pueraria phaseoloides/Melinis minutiflora, Calopogonium mucunoides/Melinis minutiflora, Stylosanthes gracilis/Panicum maximum.* Similar work is proposed with *Glycine javanica.*

Observation plots and/or palatability trials are in progress or are proposed with *Clitoria ternatea, Desmodium scorpiurus, Dolichos hosei, Pueraria thunbergiana, Desmodium uncinatum* and *Stylosanthes sundaica.*

Investigations are also in progress with *Centrosema pubescens, Pueraria phaseoloides, Calopogonium mucunoides, Stylosanthes gracilis, Crotalaria* spp., cowpeas, etc. as green manures and cover crops in horticultural activities.

Observations are made on indigenous forage legumes from zone D, including *Glycine tomentosa, Rhynchosia minima, Lotus australis, Psoralea cinerea, Desmodium campulocaulon, Sesbania aculeata, Alysicarpus rugosus, Neptunia monosperma* and *Zornia diphylla.*

PACIFIC ISLANDS

Fiji

There are two climatic zones in the Colony, the south-east or wet areas (rainfall 120 to 130 inches) and the north and north-west areas (rainfall 60 to 80 inches); there are extensive areas of shallow soil of poor quality and legume establishment is fortuitous rather than designed. There are some excellent examples of natural legume/grass mixtures, e. g. *Pueraria thunbergiana* and *Atylosia scarabaeoides* in the dry area growing with native and introduced grass species.

The cultivation of legumes for pasture and fodder is not generally practised by stock owners, although dairy farmers and smallholders occasionally grow cowpeas and other dual-purpose legumes for feeding. Many farms encourage the growth of legumes such as *Desmodium* spp., *Mimosa pudica* and *Alysicarpus vaginalis* in their pastures. Highly productive grazing has been induced by using mixtures of legumes and grasses, *Centrosema pubescens* with *Panicum maximum* or *Pueraria phaseoloides* with *Brachiaria mutica, Desmodium with Ischaemum* or *Paspalum dilatatum*, and *Stylosanthes* (creeping) in natural *Dicanthium* or *Andropogon* pastures.

Green manure legumes in sugar cane include *Stizolobium aterrimum, Vigna sinensis, Phaseolus* spp. and *Cajanus cajan.* Economic factors limiting greater use of legumes in Fiji include cost and short supply of good seed, cost of establishment and so far as green manures are concerned, a general objection on the part of small cultivators to spend time on indirect cropping which shows no immediate and visible return.

Farmers generally have not, until recently, been faced with the need to use green manures but have followed the line of least resistance in exploiting the natural resources of the soil and moving on to new areas from time to time.

Types of systems in which legumes occur are:

(*a*) sugar cane cultivation. Green manure and pulse crops already mentioned, pigeon pea (*Cajanus cajan*) widely grown for food;

(*b*) coconut plantations. Cover crops of *Centrosema* and *Calopogonium*, with natural cover comprised of *Crotalaria* spp. *Desmodium* spp. *Cassia* spp. *Phaseolus* and *Vigna* spp. More extensive use of legume covers is indicated;

(*c*) bananas. The few legumes which occur are all natural. Cowpeas have been used successfully as a cover and green manure;

(*d*) maize/rice/groundnut rotations are practised by smallholders occupied in cash-crop production.

There is a good local demand for pulses, and all common species are grown except the soyabean, which has not become popular in spite of many efforts at introduction.

The use of legumes for shelter, shade and mulch is not uncommon – *Gliricidia* and *Erythrina* are now fairly widespread. Native Fijians practise various systems of long fallow – one involving *Leucaena glauca*. Grazing systems have yet to be established but farmers are generally aware of the value of legumes and various species occur throughout all grazing areas. Experimental alternate husbandry systems on the Suffolk 4-course rotation are being developed; in the past attention has been given to the use of a fairly wide range of legumes in crop rotational schemes varying from 3 to 7 years and involving root crops, grains, pulses, green manure and cover crops and such plantation crops as bananas and citrus. Rice beans, cowpeas, various other pulses, Mauritius bean and *Crotalaria* have all had a place in these schemes.

There are large stands of *Leucaena glauca* in the Colony and it is planned to include these in local feeding experiments following the experience reported from Hawaii. This plant is commonly grazed by cattle which thrive on it, and by horses which suffer from alopecia quite commonly. The pods of *Pithecellobium saman* are commonly eaten by cattle; periodically there are cases of suspected poisoning of horses grazing in the vicinity of this tree, but no serious investigations have been possible. The fodder value of indigenous legumes is not known. Many occurring in the natural vegetation, especially species of *Cassia* (*C. mimosoides*, *C. tora* and *C. occidentalis*), *Crotalaria* and *Indigofera* are unpalatable to cattle and have little value.

Experimental work includes:

(*a*) Introduction of species, varieties and strains of fodder, food and fibre legumes, cover crops etc. This work is in collaboration with the South Pacific Commission. Reports will shortly be available. It is centred at the Plant Introduction Station at Naduruloulou.

(*b*) Agronomic studies and varietal improvement at the Principal Agricultural Station on fodder legumes, pulse crops, vegetables and green manure crops. Investigation of rotations for root crops, sugar cane and plantation crops (bananas). In animal nutrition studies at the Agricultural Station, Sigatoke, special attention is given to the establishment of grass/legume pastures, to measurements of their yields and productivity in terms of animal products; a scheme of alternate husbandry involving pulse crops and cover crops is being followed.

A list of introduced leguminous plants recorded in Fiji by B. E. V. Parham was published in the *Agricultural Journal Fiji*, for March 1949.

Hawaii

Before 1920, a considerable acreage of soilage legumes, principally lucerne, was grown to provide fresh green roughage to dairy cattle; now only a few acres of this high-protein material are grown, and its place is taken by high-yielding but low-protein crops, such as Napier grass. This is due to high cost and rents of land (fee simple land costs from $500 and upward per acre, and land rents are from $10 per acre upwards). Most of the dairies are located in suburban areas where little land is available for cultivation. Soilage legumes are expensive to produce due to high costs of hand labour for harvesting, of weed control (particularly in lucerne stands), of irrigation (essential because of periodic summer droughts), and of fertilizers (because soils are acid in general and low in available phosphate, some requiring 4 tons of lime and up to 2,000 lb. of superphosphate per acre).

The climate is highly variable in rainfall and temperature, most of the rain coming during the winter when tropical legumes are least active in growth. Soilage legumes, such as *Desmanthus virgatus* and *Leucaena glauca*, are sensitive to increase in elevation and are generally restricted to areas below 500 feet. High humidity and high temperature combine to reduce the production and persistence of lucerne, periodic outbreaks of leaf-spot diseases being particularly severe in the winter. In the humid areas the palatability of legumes falls considerably.

Legumes are not grown at all for green manure or cover crops. Sugar cane (220,000 acres) is grown in a continuous cropping system and most of the pineapple fields (70,000 acres) are grown without green manure. The same applies to coffee, fruit and nuts. Between 1900 and 1910, a number of legumes were tried in the sugar plantations, and in the 1920s the pineapple companies used legumes in the crop cycle; at one time, over 5,000 acres were planted to pigeon pea alone.

All farmers and plantation managers maintain that the high cost of land and rentals preclude the use of green manure and cover crops for soil renovation and enrichment, saying that fertility can be maintained much more cheaply by chemical fertilization. Green manure legumes are costly to grow, they require irrigation because annual tropical legumes are summer growers, and seed is not available from commercial channels.

The growers of truck crops operating on an extensive scale could profit from green manures, particularly above 2,500 feet; at these elevations, temperate legumes, such as vetch, *Lathyrus*, and field pea, are well adapted for winter production.

Species recommended for summer green manure or cover crop

A. Below 1,000 feet and supplemented by irrigation: *Crotalaria spectabilis, C. juncea, C. anagyroides, Stizolobium aterrimum, Indigofera sumatrana.*

B. Above 1,000 feet: *Vicia sativa, V. atropurpurea, Lathyrus tingitanus, L. ochrus, L. sativus* and *Medicago hispida.*

C. Perennial cover crops, up to 1,500 feet: *Desmodium canum, D. intortum* and *Indigofera endecaphylla.*

D. Perennial cover crops, above 1,500 feet: *Trifolium repens* (white or Ladino), *Lotus uliginosus, L. corniculatus* (broad-leaved) and *Trifolium pratense.*

Species sown pure or in mixtures for grazing

A. Higher elevations. Species: *Trifolium repens, T. pratense, T. arvense, Medicago hispida, M. lupulina, M. hybridum, Lotus uliginosus, L. corniculatus, Vicia sativa, V. atropurpurea.*

Seeds are sown preferably from September to November to take advantage of the autumn rains; this ensures adequate vegetative growth so that both annuals and perennials are mature when the dry season begins in April and are able to set seed. Once the species are well established, the companion grasses require to be grazed closely in early spring to encourage the growth of legumes. Pasture herbage is never harvested for hay or silage. The strains and species of *Lotus* are grazed lightly for short durations to avoid damage by trampling; birdsfoot trefoil, in particular, should be grazed in short rotations.

B. Low elevations. Species: *Desmodium canum, D. uncinatum, D. intortum, Leucaena glauca, Cajanus cajan, Pueraria phaseoloides.*

In the drier sections, sowing should again be in autumn. Associated grasses require to be kept well under control by frequent light grazings until the legumes are well established. Lime and superphosphate are applied as required. Continuous grazing or a long grazing interval is the general practice, but certain herbaceous legumes will not persist unless grazed in rotation.

Indigenous or naturalized species in natural vegetation include:

Medicago hispida, Mimosa pudica, Phaseolus lathyroides, Desmodium canum, D. uncinatum, Crotalaria incana, C. striata, C. longirostrata, Cassia leschenaulteana, C. occidentalis, Alysicarpus vaginalis, Indigofera suffruticosa, Vicia sativa. Some of these have good forage value, others little or none, while some are doubtfully or actually toxic.

Shrubby and woody legumes, including trees, are:

Acacia farnesiana, A. koa, Desmanthus virgatus, Leucaena glauca, Prosopis chilensis. The *Prosopis* is the most important tree legume of Hawaii, producing from June to November a heavy pod crop which is fed to dairy cows and pigs.

Experimental Work. The value of lime and phosphate has been noted in trials conducted by the Hawaii Agricultural Experiment Station. Responses to applications of boron and molybdenum have been obtained with lucerne; the interaction between lime and molybdenum has been observed.

An attempt has been made to evolve a satisfactory technique for emasculation or pollination of a non-toxic strain of *Indigofera endecaphylla.*

Legume/grass mixtures being tried are:

1. *Desmodium canum* in pure stand and in combination with *Paspalum dilatatum.*
2. *Desmodium intortum* interplanted with:
   (a) *Panicum purpurascens,*
   (b) *Pennisetum purpureum,*
   (c) *Paspalum dilatatum.*

As seeds of most of the tropical legumes are not available on the commercial market, the technique for their production, harvesting, threshing, cleaning and scarification is studied for strains which appear promising. The laboratory at the Hawaii Agricultural Experiment Station is adequate to undertake this work as a public service on behalf of ranchers until it can be taken over by private enterprise.

Chapter Eight

POISONOUS PLANTS AND WEEDS

Poisonous plants

Poisonous plants have been known and plant poisons have been used by man since time immemorial. Primitive peoples have used and still use arrow poisons, and they have learnt through experience of a great number of plants poisonous to man or to their domestic animals. Poisons extracted from such plants have been used for medicinal purposes, as fish poisons or insecticides and for killing enemies. They are found throughout the vegetable kingdom, from the bacteria, fungi and ferns up to the highest plants. In some families or genera poisonous plants are more common than in others and in some nearly all species are more or less poisonous. The immense legume family contains a great number of toxic or poisonous plants; in the United States alone there are more than 100 toxic leguminous species.

The plant poisons are of many different kinds; some of the most virulent ones belong to the alkaloids, others to the glucosides. Hydrocyanic or prussic acid is also very common in plants and especially in the genera *Prunus* and *Sorghum*, and among the legumes. It occurs in harmless compounds which, when broken down by ferments or enzymes, produce the highly toxic acid. This occurs when the complex nitrogenous compounds are digested in the alimentary tract. The actual enzymes are, in this case, pepsin, trypsin and erepsin. How complicated these reactions are may be understood from the following case. Extensive poisoning of sheep and cattle was reported in the Georgina river valley of western Queensland, Australia. Careful investigation showed that the poisoning was the result of the dual use by the animals of two shrubs (*Acacia georgina* and *Stenochilus maculatus*). It was found that the *Acacia* contained an enzyme which liberated the prussic acid from a glucoside occurring in the *Stenochilus*. Eaten separately, both shrubs were quite harmless.

All parts of some plants are more or less toxic. In others, only the seeds, leaves, roots or rind of the stem are dangerous. Some plants e. g. *Phytolacca*, *Sambucus* and *Toxicodendron*, have more of a reputation for poisoning man than animals; others, e. g. *Equise-*

setum, *Leucaena glauca*, *Stipa vaseyi* are particularly dangerous to horses; still others, such as *Delphinium* and *Lupinus*, to sheep. Many slightly poisonous plants can be safely fed to farm animals in small quantities or in admixture with other forage plants, but may cause poisoning in other cases.

Certain plants, e. g. *Astragalus convallarius*, are normally quite harmless, but, when growing on soils with a high selenium content, they substitute this toxic element for a harmless substance, such as sulphur, in their metabolism and become poisonous. Other plants may become toxic by taking up an excess of molybdenum on alkaline soils rich in this element. This poisoning can be counteracted by feeding copper sulphate to the affected animals. In South Africa, there are allegedly " poisonous " and "safe " soils even on the same farm and it is reported that on certain soils lucerne and even non-legumes are usually deadly poisonous.

The common sweet clovers (*Melilotus* spp.) contain a substance coumarine, which has a vanilla-like odour. It is usually quite harmless but spoiled sweet clover hay and poorly preserved sweet clover silage often become toxic because of a decomposition product of coumarine causing external and internal bleeding.

In this connection the common " bloat " of cattle should be mentioned. It occurs when the beasts graze forage mixtures in which succulent legumes predominate. It can be reduced by using more grasses in the pasture mixtures, giving the livestock access to dry hay and straw and to plenty of salt and water, and by not turning the animals into the pastures when they are too hungry or when the plants are covered with dew or raindrops.

As mentioned above, a great number of leguminous plants are more or less poisonous, but it is impossible to mention all of them here. Reference should be made to the species descriptions in Part II wherein toxic plants are further denoted by an asterisk. Some cases of more general interest will, however, be discussed below.

The genus *Astragalus* has many poisonous species, but others such as *A. arenarius*, *A. cicer*, *A. glycyphyllum*, *A. hypoglottis* and *A. sinensis* are non-toxic. Some of the toxic species cause a disease called locoism. The genus *Cassia* is generally more or less toxic, but *C. occidentalis* and *C. tora* are non-poisonous. Hay of the chick-pea (*Cicer arietinum*) is toxic but not the seed. Most of the *Crotalaria* species are toxic, with the exceptions of *C. anagyroides*, *C. hirsuta*, *C. incana*, *C. intermedia*, *C. lanceolata*, *C. striata* and *C. usaramoensis*. The roots of *Derris elliptica* contain rotenone and other toxic compounds, used as fish poisons or insecticides. Coloured but not white seeds of the hyacinth bean (*Dolichos lablab*) contain prussic acid and are therefore poisonous. Goats' rue (*Galega

officinalis) is somewhat poisonous but can still be used for fodder in small quantities. The genus *Indigofera* comprises certain species which apparently cannot be eaten by stock with impunity (*I. hirsuta*), others which are sometimes poisonous (*I. endecaphylla*), and a great many species which are invariably poisonous. Many *Lathyrus* species are somewhat poisonous, especially the seeds, but *L. cicera*, *L. hirsutus*, *L. sativus* and several others are still used for forage and some even for human consumption. In the tropics, *Leucaena glauca*, which is poisonous to horses and mules, is much used as a shade tree and for soil cover and green manure, but also to a great extent as fodder for ruminants.

Many lupins (*Lupinus* spp.) when in pod are poisonous to sheep; a few are poisonous at other times and to other animals. However, most of the wild species of this large genus appear to be grazed, without harmful results, though to a rather limited extent prior to flowering. Strains practically free from the poisonous alkaloid, lupinine, have been developed in *L. albus*, *L. angustifolius* and *L. luteus* (sweet lupins). The North American *L. caudatus* is especially poisonous to cattle, horses and somewhat to sheep, and yet is at the same time very palatable.

Some varieties of the lima bean (*Phaseolus lunatus*) with coloured seeds contain prussic acid and are poisonous, whereas others are used to a great extent for human consumption. Among the *Tephrosia* spp. many are poisonous (*T. candida*, *T. purpurea*, *T. toxicaria* and *T. vogelii*), some being used as fish poisons; the foliage is poisonous, but the fleshy roots are devoured by hogs.

Among the true clovers (*Trifolium* spp.), alsike (*T. hybridum*) is sometimes poisonous to horses when eaten in large quantities and certain strains of white clover (*T. repens*) can give rise to prussic acid. The seeds of the ervil or bitter vetch (*Vicia ervilia*) which are much used in southern Europe and Turkey as concentrates are somewhat poisonous and care must be taken not to offer too much to livestock or sheep. All parts, and especially the seeds of *Laburnum anagyroides* syn. *Cytisus laburnum* are poisonous. A large number of Australian legumes are toxic to domestic livestock and in some cases cause serious sickness and losses. Genera represented are: *Castanospermum*, *Erythrophleum*, *Gompholobium*, *Goodia*, *Gastrolobium*, *Isotropis*, and *Swainsona*.

Gorse (*Ulex europaeus*) has become established on dunes, beaches, and elsewhere on the Atlantic and Pacific coasts of the United States. Being highly inflammable, it may become a serious fire hazard and was one of the prime causes of the destruction of the town of Brandon, Oregon, U.S.A. by forest fire in 1936. In addition, although gorse is used in Europe for fodder, a toxic alkaloid occurs in its seeds and it is under suspicion as a potentially poisonous plant.

As a general rule, it may be stated that weeds are plants growing where they are not desired. Many weeds grow in areas where they are not well adapted, but may still thrive in the absence of competition. Usually they are favoured by vigorous reproductive powers and great tolerance to extremes of heat or cold, drought or excessive moisture, etc. They often show great persistence due to possession of hard seeds, underground rootstocks or tubers; frequently their distribution is favoured by special attachments to their fruits or seeds, enabling them to be spread by wind or passing animals. Many crops may, especially under favourable conditions, behave as pests, preventing the successful cultivation of other plants in fields where they have run wild. The control and eradication of weeds cause a farmer much work and expense, and often force him to fallow his fields, thus losing a whole crop. The interpolation of a legume/grass ley or mixture in a crop sequence may help to reduce the incidence of arable weeds. Previously, the farmer had to rely mainly upon mechanical remedies for fighting weeds, but now the selective chemical compounds make it possible to kill the weeds without injuring the associated crops.

Weeds belong to practically all plant families, but certain families have more than others; this is especially so in the Compositae, Gramineae and Cruciferae. The Leguminosae are not bad weeds as a group, but there are exceptions; under favourable conditions many species, usually considered quite harmless, may turn into pests difficult to eradicate. A few examples will be mentioned.

Certain legumes have fruits with hooks or thorns which cause them to adhere to the hides or wool of animals or the clothes of passing people. The fruit is later dropped in other places and the species in question are thus able to spread rapidly over great areas, and become pests. Among the better known of such species are the bur clovers (*Medicago arabica*, *M. hispida*, *M. minima* and others) and the creeping beggarweed (*Desmodium canum*). They are also noxious as they become entangled in the wool of sheep and reduce the quality of the fleece.

The yellow annual sweet clover (*Melilotus indica*) is a bad weed in wheat fields in Australia where the importation of its seed is completely prohibited. Yellow and white sweet clover (*M. officinalis* and *M. alba*) are also sometimes considered to be weeds in parts of Europe and America.

In pastures, the shattering habit and natural re-seeding ability of many leguminous species, especially the annuals, is very valuable. In crop rotations this is not always the case, however, and some of these otherwise valuable species may thus turn into weeds. This may be the case with bur clovers, hop clovers and black medick

(*Medicago* spp. and *Trifolium* spp.) and many plants of other genera. *Cassia occidentalis*, *Crotalaria longirostrata* and *Pithecellobium dulce* are considered as pests in certain localities of Hawaii, but elsewhere as valuable crops. The mesquites (*Prosopis* spp.), covering vast dryland areas in Central America and appreciated as browse plants, are sometimes difficult to eradicate when the land is required for other purposes. In that case they must be regarded as weeds. *Mimosa invisa*, which in Indonesia is a fodder and cover plant, is in many other countries, such as the Philippines and Fiji, considered as a noxious weed. The central Asiatic legume camelthorn (*Alhagi pseudalhagi* syn. *A. camelorum*) is a serious weed in cultivated ground both in certain parts of the United States and in South Australia, and *Cytisus scoparius*, *Genista tinctoria*, herbaceous species of *Cassia* (see *Chamaecrista*) and *Lespedeza violacea* are weeds in California.

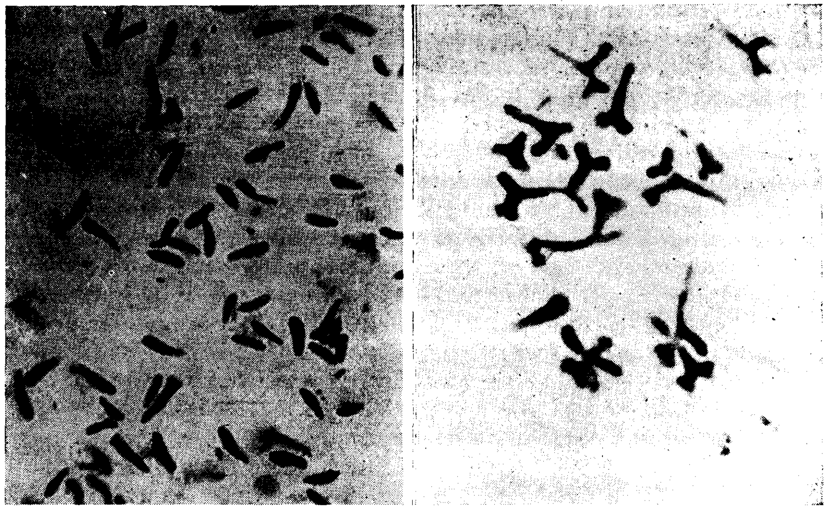
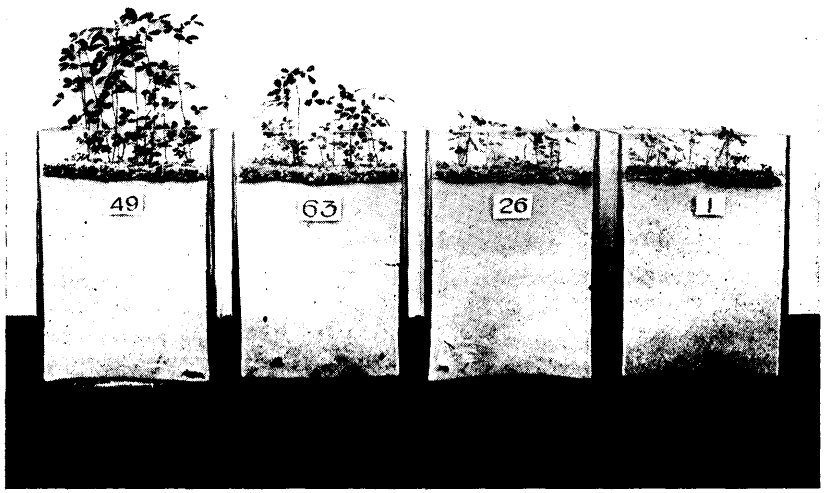


PLATE 14. Nodule bacteria under high magnification
(Left) *Trifolium* bacteria; (Right) Irregular x and y shapes (U.S.D.A.)

PLATE 15. Lucerne in sterilized sand to which strains of *Rhizobium meliloti* have been introduced. 49 = highly effective strain fixing adequate nitrogen;
63 = moderately effective strain;
26 = ineffective strain;
1 = inoculated control.



(Photos by courtesy of the Waite Agricultural Research Institute, Adelaide, Australia)

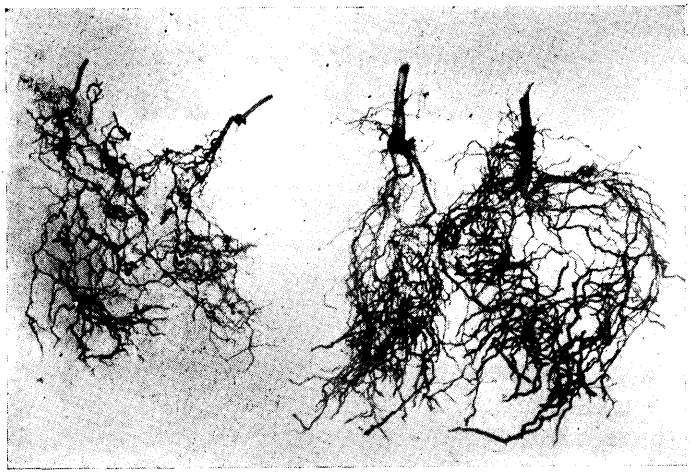


PLATE 16. Root systems of lucerne following inoculation by strains of *Rhizobium meliloti* (left: ineffective; right: effective). Note differences in amount of root growth and in shape, size and disposition of nodules.

(Photos by courtesy of the Waite Agricultural Research Institute, Adelaide, Australia)

PLATE 17. Comparative morphology and disposition on the root system of subterranean clover of nodules following inoculation with strains of *Rhizobium trifolii* (left: ineffective; right: effective).

PLATE 18. Nodule clusters of strains of *Rhizobium meliloti* on roots of lucerne (above: ineffective; below: effective). Note outstanding differences in nodule morphology between effective and ineffective associations.

(Photos by courtesy of the Waite Agricultural Research Institute, Adelaide, Australia)

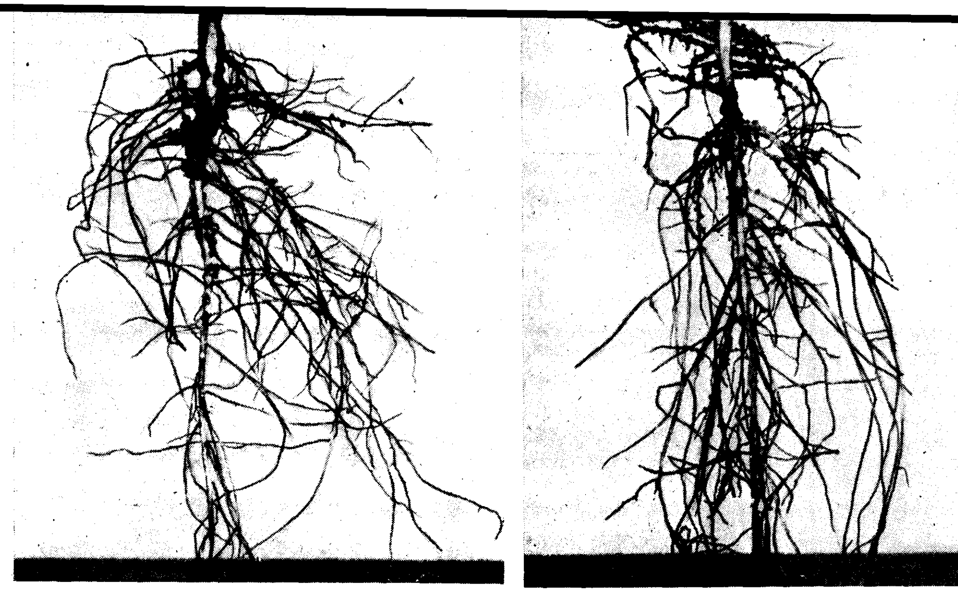


PLATE 19. Root systems of *Vicia faba*, showing an effective (left) and an ineffective (right) association of two strains of *Rhizobium leguminosarum*. Note the clusters of large effective nodules in the vicinity of the main roots, and the scattered small ineffective nodules extending over lateral roots.

PLATE 20. Plant of subterraneum clover from same field as plants in Plate 21. Nodule formation is restricted to limited pockets in which an indigenous strain of *Rhizobium trifolii* was present. Under conditions of such sub-optimal nodulation, nitrogen supply may prove to be a limiting factor later in the season, and yield will be depressed.

PLATE 21. Plants of subterranean clover (*Trifolium subterraneum*) from a first-year sowing where inoculated seed was not used. The gradation in plant size and vigour is a reflection of inadequate nodulation extending to a complete absence of nodules in the smallest plants. These are likely to succumb to fungal infection and not set seed, and hence a patchy establishment will result.

(Photos by courtesy of the Waite Agricultural Research Institute, Adelaide, Australia)

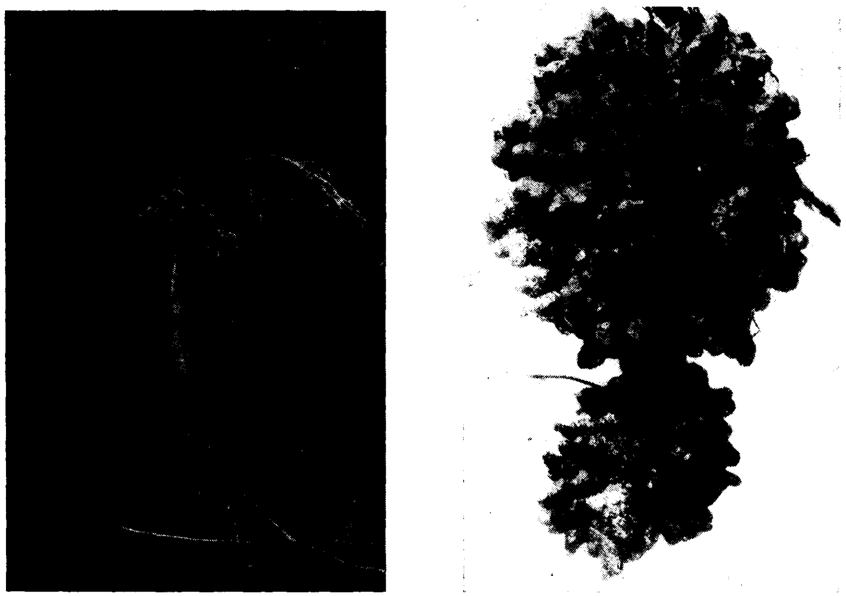


Plate 22. Types of nodulation produced by effective strains of bacteria on different legumes. (Top left) *Lespedeza* sp.; (top right) *Stizolobium deeringianum*; (bottom left) *Vigna sinensis;* (bottom right) *Trifolium pratense.*

(Photos by courtesy of the United States Department of Agriculture)

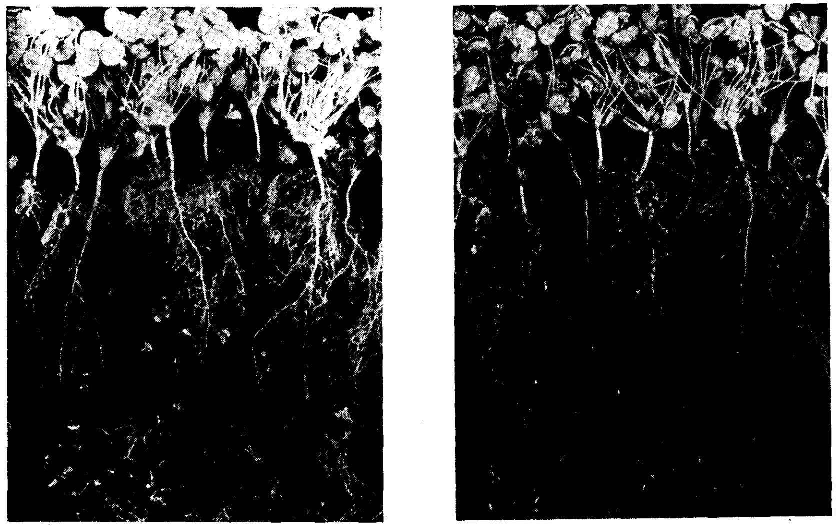


Plate 23. Plants of subterranean clover grown in lateritic soil in plots in the greenhouse (Left) Plants inoculated with an effective strain of *Rhizobium trifolii* show a profusion of small, healthy nodules, particularly in the upper parts of the root system. (Right) In plants which have not been inoculated the few large fan-shaped nodules present have been formed from an indigenous strain. It is unlikely that these nodules can continue adequately to supply the nitrogen demands of the plant.

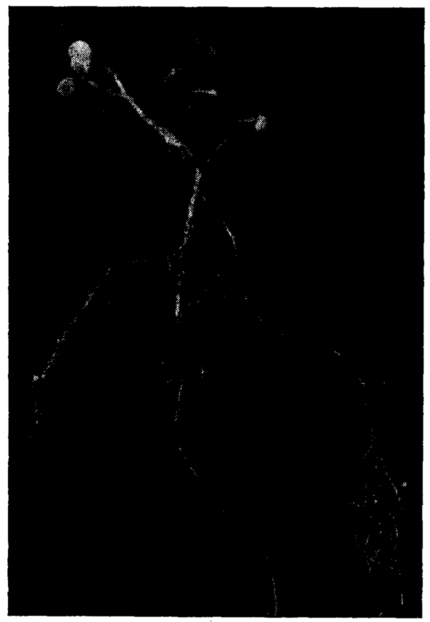


Plate 24. Plant of subterranean clover showing apparently ineffective nodulation from an indigenous strain in a lateritic soil. The single pocket of large nodules in the right-hand corner is probably contributing most of the nitrogen supply to this plant.

(Photos by courtesy of the Waite Agricultural Research Institute, Adelaide, Australia)

PLATE 25. Effect of four strains of lucerne/sweet clover bacteria on lucerne. The third culture from the left was definitely parasitic.

PLATE 26. Inoculation of crimson clover (*Trifolium incarnatum*). Total failure without inoculation, excellent growth with inoculation of seed.

(Photos by courtesy of the U. S. Department of Agriculture)

CHAPTER NINE

THE SIGNIFICANCE OF SYMBIOTIC NITROGEN FIXATION*

Although writings of antiquity have indicated that ancient agriculturists appreciated the value of legumes in improving and sustaining soil fertility, it was not until towards the end of the nineteenth century that Lawes and Gilbert at Rothamsted showed that this particular property of legumes was inherent in their ability to add nitrogen to the soil. Their interest in this problem was aroused by an outstanding series of experiments conducted by Hellriegel and Wilfarth in Germany and published in 1888. As early as 1838, Jean Baptiste Boussingault had experimentally demonstrated that when wheat, clover and peas were grown in pots, the gain in nitrogen content of the plants was equalled by the loss of nitrogen from the soil only in the case of wheat; in both clover and peas the loss of nitrogen from the soil was disproportionately small and hence an apparent over-all gain in the total nitrogen of these legumes was obtained. Boussingault did not fully appreciate the significance of his discovery, nor did he recognize that herein lay an all-important distinction between leguminous and non-leguminous plants. Hellriegel and Wilfarth demonstrated that such gains in nitrogen in peas took place only in the presence of soil micro-organisms and that the root nodules of legumes were intimately concerned. In America, Marshall Ward in 1887 showed that root nodules were formed only in the presence of soil bacteria. The chain of evidence was completed in 1888 by Beijerinck in Holland by the isolation of the nitrogen-fixing bacteria from the nodules and from soil, and the generic name *Rhizobium* was given to them.

It can thus be seen that it is not the leguminous plant itself which is able to " fix " or utilize gaseous nitrogen from the atmosphere, but the bacteria, the rhizobia, in the root nodules. Should the root nodules be absent or ineffective, the plant must still fulfil its nitrogen requirements by drawing upon the nitrogen supply of the soil. Pasture legumes usually contain about twice as much nitrogen per ton of dry hay as grasses; in considering the ability of legumes to contribute to soil fertility, it is therefore important that nodulation shall be effective, otherwise legumes may, in fact, deplete reserves of soil nitrogen faster than grasses and cereals. Some consideration

* This section was prepared by J. R. Harris on behalf of Professor H. C. Trumble.

must, therefore, be given to assessing the circumstances under which these rhizobia will form compatible symbiotic association with the leguminous host plant.

The function of the nodule

The earliest conceptions of the nature and functions of legume root nodules tended to regard them either as products of some pathological disorder or as storage organs. Following Ward's (1887) proof that nodule formation results from bacterial infection came the realization that the nodule is a characteristic feature of most members of the Leguminosae and has nutritional significance. This is particularly true of the sub-families Faboideae and Mimosoideae with a few consistent exceptions in the sub-family Caesalpinioideae, which are characteristically devoid of nodules. These include *Gymnocladus*, *Gleditschia*, *Cassia*, *Cercis*, *Caesalpinia*, *Saraca* and *Schotia*. Altogether seventy-seven species belonging to seventeen genera do not form nodules under any known conditions, but current records are imperfect; published observations refer to only about 1,000 of the 10,000 or more species of the Leguminosae as a whole (Allen and Allen, 1947).

Nodule production by rhizobia is limited to the Leguminosae, although certain non-leguminous species of *Alnus*, *Coriaria*, *Elaeagnus*, *Ceanothus*, *Myrica*, *Podocarpus*, *Casuarina* and *Zygophyllum* produce nodules containing organisms other than *Rhizobium;* their relation to nitrogen nutrition is debatable.

The shape, number and distribution of the nodules vary considerably from plant to plant. Cultivated annual herbs usually have large, fleshy, spherical, pyriform, clavate, or flabellate nodules, borne singly or in clusters, and distributed especially about the tap-roots or first-formed lateral roots. Perennial or biennial plants tend to develop smaller nodules, elongated, clustered and widely distributed; new nodules are formed on the young parts of the root system. The total number of nodules on a single plant ranges from a few to several thousands, although the mere presence of numerous nodules is not necessarily a criterion of adequate fixation of nitrogen. There is also the possibility that nodular growths on legume roots may be due to causes other than rhizobia. Infection by nematodes or eelworms of the genera *Heterodera* or *Anguillulina* may produce small galls or root-knots giving a false impression of nodulation. Infection by the crown-gall bacterium, *Agrobacterium tumefaciens*, may also produce swollen lesions at or near the crown of the root; these are usually morphologically irregular, whereas true nodules are cortical outgrowths with regular structure.

The bacterial genus, Rhizobium

The bacteria are small, rod-shaped cells, motile at first by peripheral flagella, but later becoming non-motile and swollen, banded and irregular, the so-called " bacteroids ", which are especially common in the nodule and rarer in pure cultures. Earlier hypotheses postulated a complex life cycle in which a series of forms were exhibited, but recent studies have failed to find significant correlations of functions associated with morphological differences.

Biochemically, rhizobia are able to utilize a range of monosaccharide and disaccharide sugars, but are feebly proteolytic. In the absence of their appropriate host plants, nitrogen is not fixed. Nitrates are slowly reduced to nitrites, which are not available to the cells as sources of nitrogen. Usually the basic nitrogen content of rhizobial cells is characteristically low, of the order of 4 to 5 per cent. which is roughly half that of most bacteria. A polysaccharide nitrogen-free gum is elaborated giving a translucent mucoid colony formation on solid culture media. A number of growth factors are essential and strains are known which require biotin, thiamine, riboflavin, pyridozine, β-alanine, nicotinic, para-aminobenzoic and pantothenic acids. Rhizobia from clover, lucerne, peas and beans are called " fast growers " because they produce turbidity in broth and abundant growth on solid media within 5 to 7 days; the rhizobia from soyabean, lupin and cowpea take 9 to 12 days or longer and are termed " slow-growers ". The two general groups show somewhat different physiological tendencies in their responses to growth factors and their carbon and nitrogen requirements, the slow-growers being the more fastidious.

With respect to physical factors, most rhizobia show optimal growth between 29° and 31° C., but strains of *Rh.meliloti* are known with an optimum of about 35° C. All rhizobia have similar tolerance to alkalinity with a limit of about pH 9.6; they are differently affected by acidity, *Rh. meliloti* being least tolerant with a limit of about pH 5.0, and *Rh. lupini* and *Rh. japonicum* most tolerant with limits of pH 3.2 to 4.2.

Although rhizobia are essentially aerobic organisms, their growth either in soil or in the nodule is under conditions of oxygen content below that of atmospheric air. In fact, oxygen tensions of 5 per cent. or less are tolerated with but slight loss in activity; in artificial media the oxidation/reduction potential is an important factor conditioning growth, and slightly reducing conditions are preferred.

The natural habitat of rhizobia is soil; the organisms may adopt a free existence apart from their natural hosts and persist for many years. Usually the more fertile the soil, the greater the numbers

of rhizobia it will contain, but in soils of low fertility some rhizobial strains either have never been introduced or completely lack the power to persist in competition with other elements of the soil microflora. However, if one accepts the ubiquity of micro-organisms as the general rule, it seems more than likely that some of these strains are not as well adapted as others to an indigenous life in the soil. Some plants, e. g. clovers or peas, respond less frequently to artificial inoculation than others, e. g. medicks or soyabeans. Not only is it necessary at times to use inoculation to introduce the appropriate rhizobia, but also to sustain the rhizobial population at an adequate level following long periods of absence of that legume in a crop rotation.

Species' relationships and cross-inoculation groups

One bacterial strain is able to infect the root system and produce nodules on any of a group of related legumes, but not usually upon legumes of other groups. Another strain may similarly nodulate another group of related legumes, but there is no overlap of plants from group to group. This has led to the recognition of the so-called cross-inoculation groups of host legumes, and is the basis adopted for species' differentiation within the genus *Rhizobium*. Six such groupings have been raised to specific rank, although at least one is somewhat heterogeneous and contains groups of uncertain relationship.

The first five of these groups plus the soyabean sub-group are well marked. The specific name *Rh. japonicum* is sometimes restricted to the soyabean group, and the cowpea and strain-specific groups are not given specific designation. In either case the taxonomic position is rather unsatisfactory; obviously this large assemblage is rather heterogeneous and there are probably other groups within this group. The strain-specific groups are relatively restricted in the range of organisms able to nodulate them and cross-inoculation is apparently not possible.

Most of the non-cultivated legumes of the indigenous flora of both temperate and tropical regions belong to this ill-defined cowpea group, and their cross-inoculation relationships therefore await more precise definition.

J. K. Wilson (1939, 1944) has shown that the boundaries of these groups are not always rigidly defined, and that there may be some promiscuity in cross-inoculation groups. Despite these objections, however, the cross-inoculation grouping still remains the most convenient physiological basis for species differentiation within the genus *Rhizobium* and more reliable than biochemical, serological or phage-specificity methods.

Table XXX. Species Relationships

Bacterial Strains	Plant Groups	Genera and Species
1. *Rhizobium meliloti*	Lucerne - medick melilot	*Medicago, Melilotus, Trigonella*
2. *Rh. trifolii*	Clover	*Trifolium.*
3. *Rh. leguminosarum*	Pea	*Lathyrus, Lens, Pisum, Vicia*
4. *Rh. phaseoli*	Bean	*Phaseolus* (part only) vegetable, navy haricot and case-knife beans
5. *Rh. lupini*	Lupin	*Lupinus, Ornithopus*
6. *Rh. japonicum*	(*i*) Soyabean	*Glycine*
	(*ii*) Cowpea	*Acacia, Albrus, Albizzia, Alysicarpus, Andira, Arachis, Baptisia, Cajanus, Canavalia, Clianthus, Crotalaria, Cytisus, Cyamopsis, Derris, Desmodium, Dolichos, Enterolobium, Erythrina, Genista, Hardenbergia, Hymenaea, Indigofera, Inga, Kennedya, Lespedeza, Lonchocarpus, Mucuna, Parkia, Phaseolus* (part), *Piscidia, Pithecellobium, Platylobium, Pongamia, Pterocarpus, Pueraria, Pultenaea, Stylosanthes, Stizolobium, Tephrosia, Ulex, Vigna, Voandzeia.*
	(*iii*) Strain-specific	Species of: *Amorpha* *Amphicarpa* *Caragana* *Cicer* *Coronilla* *Dalea* *Lotus* *Onobrychis* *Robinia* *Sesbania* *Strophostyles*

Effective and ineffective nodulation

Although the symbiotic association between the plant and the bacteria in the nodules leads to the fixation of gaseous nitrogen, the actual amount of fixation in any one nodule varies widely. Under optimal circumstances, fixation of nitrogen may be rapid and continuous throughout the growing season; under adverse circumstances the period of fixation may be transient and little nitrogen may be fixed. In the first case the association between plant and organism is said to be " effective ", and in the second case " ineffective ".

Thornton (1939) has shown that the major difference between an effective and an ineffective association is in the duration of the fixation process; the rate of fixation per unit volume of infected cells while in progress is not appreciably different in either case.

Within one cross-inoculation group, strains of bacteria vary in their power to form effective, ineffective or intermediate associations; thus strains are classified as highly effective, moderately effective, intermediate, ineffective and highly ineffective. Usually this characteristic is the main factor limiting the value of the symbiotic association, but Nutman (1946, 1949) has shown that there are also limiting plant factors which he terms " responsive " or " unresponsive " and which are determined by genetic factors. Under ideal circumstances, the leguminous host plant should have highly effective nodulation, so that nitrogen will never become limiting and the plant will be independent of soil nitrogen.

Under favourable circumstances, a strain of *Rhizobium* is able to infect the root system of any plant belonging to the one cross-inoculation group, but this character of ineffectiveness is quite separate from its character of effectiveness. One strain may form an effective association with one host within the cross-inoculation group, show intermediate effectiveness with another, and be quite ineffective with a third. Another strain may show a parallel pattern of effectiveness and ineffectiveness, or be wholly effective or wholly ineffective over the three hosts, or have a pattern of effectiveness or ineffectiveness differently distributed to the other. This sort of behaviour has been noted in all cross-inoculation groups. Strong (1937) has shown typical relationship between four strains of *Rhizobium trifolii* and red, white and subterranean clovers (values in milligrams of nitrogen per set of eight plants).

Legume	Strain of *Rhizobium*			
	RT-1	*RT-16*	*RT-8*	*RT-13*
Red clover	51.4	34.3	2.8	1.9
White clover	59.6	46.5	10.5	7.0
Subterranean clover	7.9	7.2	138.5	153.5

Strain RT-1 is better than strain RT-16 for red and white clovers, but both are ineffective for subterranean clover. Strains RT-8 and RT-13 are effective for subterranean clover, but ineffective for red and white clovers.

The nodulation pattern of an ineffective association has a characteristic appearance. Usually there is a very large number of small, hard, spherical, white nodules scattered over the whole of the root system, which tends to be long and ramifying with relatively few laterals. This contrasts with the effective picture, in which

the number and distribution of the nodules are relatively restricted; groups of large, pinkish, fleshy nodules of various shapes are clustered in the vicinity of the crown and the first-formed secondary roots. If an effective nodule is sliced longitudinally it will usually be found to contain a central spot of bright pink to scarlet tissue, due to the production of the pigment leghaemoglobin, closely related to the haemoglobin of the blood. Leghaemoglobin is produced only in mature effective nodules during active stages of nitrogen fixation and in the youngest lobes of perennial nodules. It is found only in the nodular tissues which are packed with rhizobia, and is formed as the bacteroid tissues are differentiated. Should nitrogen fixation cease, it breaks down to green legcholeglobin. The appearance of a green spot in the nodule tissue is good evidence that nitrogen fixation has ceased. Chen and Thornton (1940) have shown that another character distinguishing effective and ineffective nodules is the volume of the infected nodular tissue. In effective nodules this may be three to five times that of ineffective nodules. It thus seems that an ineffective nodule is one in which development is prematurely halted and no further growth is made.

It has been suggested that strains of rhizobia found to be indigenous in many soils are predominantly of intermediate or moderate effectiveness. It has also been suggested that legume failure in some areas is due to a dominance of quite ineffective strains. In Great Britain, Thornton (1947) found 37 per cent. ineffectiveness in some 463 rhizobia strains from clover, particularly those from hill pastures. Umbreit (1944) found about 25 per cent. ineffectiveness in strains from soyabeans isolated in the Wisconsin area. Leonard (1930) found a failure in peas to be due to ineffective nodulation. The few comprehensive surveys are not very conclusive; for the most part, deficiency in rhizobia is more of a problem than strong opposition from established ineffective strains; but where the rhizobial population is low in any case, it is better to attempt to build up a population of highly effective rhizobia of proved performance than to run the risk of building up the population of strains already indigenous, but of unproved ability. This is a further fact supporting the use of artificial inoculation of legume seeds with their appropriate rhizobia.

Development of the nodule

Nodulation usually takes place at about the stage of emergence of the first true leaf. The rhizobia gain access to the plant by penetration of the root hairs. A large number of root hairs may be infected but only a small proportion of these develop into nodules. In the immediate neighbourhood of those root hairs, rhizobia are stimulated to proliferate, apparently due to products excreted by

the plant roots. Such stimulation is non-specific and bacteria other than rhizobia in the rhizosphere may also respond. Proliferation of the rhizobia causes a curling of the root hairs due to auxin-like hormonal secretions; at the points of curling, the bacteria penetrate the cell and align themselves within a strand or thread growing directly towards the basal cell. In most plants, this infection thread permeates the outer cells of the root cortex; in the soyabean penetration proceeds only as far as the first five or six cell layers of the thick cortical parenchyma of the tap root, but may reach the pericycle in lateral roots.

Release of rhizobia from the infection thread takes place in the cortical tissues and the rhizobia penetrate the cells and proliferate there. Concurrently, these and neighbouring cells are stimulated to divide. According to Wipf and Cooper (1938), infected cells of nodules of clover, vetch and pea are regularly tetraploid; hypotheses suggest that either the rhizobia secrete hormonal substances capable of inducing polyploidy, or alternatively that sites of nodule formation are limited to areas in which one or more tetraploid cells already exist in the cortical tissue. Nutman (1948, 1949) concluded that the sum total of lateral roots and nodules, whether effective or ineffective, is relatively constant and controlled by hereditary factors operative within the plant. Consequently, infection by rhizobia is believed to be possible only at predetermined foci corresponding to the site of formation of lateral roots. Originally, Thimann (1938) had postulated that the nodule was merely a shapeless mass of parenchymatous tissue, essentially a lateral root prevented from further elongation. Although Nutman's work supports this hypothesis, most workers claim that histological evidence of nodule structure renders this view unacceptable.

The histological patterns of nodules from widely different species are remarkably similar. A median longitudinal section shows four conspicuous zones. The exterior consists of a spongy layer of loosely packed cortical parenchyma. Within this the nodule cortex contains elements of a peripheral vascular system united with the primary xylem groups of the root stele. The innermost zone is the bacteroid area of plant cells packed with rhizobia. Between the outer boundary of the bacteria-filled tissue and the ends of the vascular branches is a compact zone of small, actively-dividing but non-invaded cells of intense meristematic activity. The gross morphology of the nodule is largely determined by the host plant itself and the disposition of this meristematic zone.

In senescence, nitrogen fixation ceases as indicated by the appearance of green legcholeglobin. The longevity of the nodule is closely related to the growth habits of the host. On herbaceous plants, ineffective nodules begin to degenerate on about the seventh day, but effective nodules may remain intact from five to ten times longer. On woody plants, nodules persist longer, sometimes for

years; annual lobes may frequently be formed. When nodules degenerate, there is a general browning of all tissues, wrinkling of the surfaces and a softening of pulpy tissues, at which stage they are usually sloughed off at the narrow point of connection to the root.

The carbon/nitrogen ratio is important in controlling nodule activity. Any sudden change which may markedly restrict carbohydrate supply may induce changes in the nodule. Fruiting, extremes of temperature or soil moisture content, defoliation and pronounced shading will all lead to a reduction of carbohydrate supply, and cessation of fixation. The red colour may change to green, but will be developed again in new centres if carbohydrate supply is replenished. If there is no such return to equilibrium, necrosis begins in the oldest areas of the bacteroid tissue and gradually extends to involve other tissues, until final degeneration or sloughing off occurs. Nodules may also be lost when eaten by soil predators, until only a hollow shell remains; although little precise information is available, this may be important particularly in plants with woody roots.

Factors affecting nodulation and nitrogen fixation

The importance of the carbon/nitrogen (or carbohydrate/nitrogen) ratio of the sap has been mentioned. Modern theories of nitrogen fixation suggest that nitrogen gas is reduced to ammonia, which is in turn combined with alphaketodicarboxylic acids, such as glutamic acid. Transamination and decarboxylation lead to the formation of other amino acids and the various combinations of these amino units lead to protein synthesis. The rate of protein synthesis is intimately associated with the growth rate of the plant, and any unbalance in carbohydrate or nitrogen supply will create a demand for the other component.

Under conditions of a steady slow rate of photosynthesis, the carbohydrate supply to the nodule is assured and if an effective symbiotic association is present, nitrogen is fixed at a rate which maintains the carbon/nitrogen equilibrium. If photosynthesis is increased, carbohydrate supply is increased and the nitrogen demand is increased accordingly; if carbohydrate falls to a low level, or extraneous sources of nitrogen are freely available, the carbohydrate/nitrogen ratio narrows and the rate of fixation is depressed until it may cease entirely.

Any factors which increase the rate of photosynthesis, and hence carbohydrate, may increase nitrogen fixation. An increase in light intensity, an increase in partial pressure of carbon dioxide in the atmosphere, or even an extraneous supply of carbohydrate

will tend to increase the rate of fixation; but it is also possible for the carbohydrate level to rise so high that assimilation of free nitrogen is adversely affected and fixation is halted. In practice, depression of the rate of nitrogen fixation is usually due to an extraneous source of readily assimilable nitrogen. If combined nitrogen is applied to legumes as a fertilizer, the uptake of nitrogen by the plant may sustain such a narrow carbon/nitrogen ratio that fixation is depressed; if this continues for very long, degeneration of the nodule begins. It is suggested that under these circumstances the presence of the nodule on the host is more deleterious than useful, and that the rhizobia enter a parasitic phase. Some workers dispute any idea of real parasitism, but the drain of carbohydrate to the nodules is disadvantageous to some degree at least.

The carbon/nitrogen ratio also affects the development of nodules by the plant. A high level of combined nitrogen in the soil will prevent deformation of the root hairs and hence entry of the bacteria will be precluded and no nodules formed. Where there is little or no available nitrogen in the soil and the plant is entirely dependent upon symbiotic fixation following germination and prior to the development of the symbiotic system, the plant enters a period of nitrogen hunger, when all the reserves in the seed are utilized. This period generally lasts only about a week, or longer if the symbiotic system is not readily developed. To shorten this period of nitrogen starvation, it is desirable artificially to inoculate the seed with rhizobia so that there is no undue delay in nodule development due to absence of the organism. If delay is prolonged, such an excess of carbohydrate accumulates in the plant that nodulation cannot take place until a little combined nitrogen has been added. The wider the carbon/nitrogen ratio becomes, due to any of the causes indicated previously, the greater is the degree of nodulation, and the greater the scatter of nodules over the root surface, even though all are effective.

Although numerous investigators have sought to justify the hypothesis that grasses grow better in association with legumes due to nitrogen excretions through the growing season, the evidence suggests that such excretion is rare under field conditions. Virtanen and his co-workers at Helsinki first showed that peas excreted 10 to 20 per cent. of the total nitrogen fixed, and occasionally values as high as 50 per cent. were obtained. Wilson and his school at Wisconsin, Thornton at Rothamsted, Bond at Glasgow, and Trumble, Strong and Shapter at Adelaide all failed to find significant excretion over the growing season.

It is now realised that the Helsinki results were due to cool temperatures and long periods of daylight, circumstances under which photosynthesis did not out-distance the assimilation of free nitrogen. Hence a narrow carbon/nitrogen ration was maintained favouring nitrogen excretion, particularly as aspartic acid and

alanine. At higher temperatures and light intensities the carbon/nitrogen ratio remains sufficiently wide to preclude possibilities of significant excretion. Trumble and Strong (1937) conclude that subterranean clover is unable to contribute to the nitrogen demands of associate plants until there is mineralization of decayed and sloughed root tissues at the end of the growing season.

Phosphorus is an important element influencing symbiotic nitrogen fixation. The rate of protein synthesis is low in soils deficient in phosphorus; where nodulation has taken place, nitrogen fixation proceeds until the accumulation of so much soluble nitrogen forces the reaction to cease. Phosphorus-deficient plants are stunted and intensely dark green in colour due to their high chlorophyll content. Phosphorus is also important in relation to the earlier infection stages of nodulation. In this case the effect is directly upon the bacteria and not the plant. For the rhizobia to migrate through the soil towards the root system the cells must be in a motile, flagellate state; phosphorus has a pronounced stimulatory effect upon retention of this motile state. This fact is frequently utilized in the artificial inoculation of the seed by cultures of rhizobia, when small amounts of soluble phosphate are added to the suspension of bacteria. Phosphorus also undoubtedly plays a most important part in maintaining the rhizobial population at a high level in the soil. Applications of superphosphate to the soil usually have the effect of markedly stimulating numbers of organisms of the bacterial flora, and rhizobia similarly respond. There is some evidence that on lateritic soils in southern Australia, continued phosphate dressings are necessary to maintain the rhizobial population at such a level that failure of clover will not take place in the second and subsequent years in sown pastures.

Calcium is important in both the nutrition of the legume and of the rhizobia. The calcium content of legumes is about three times that of grasses on the basis of weight of dry hay. Consequently a leguminous crop may respond to liming where a non-legume may not. But calcium has an important effect on the rhizobial population in the soil. McCalla (1937) has shown that the concentration of available calcium needs to be relatively high to sustain an active rhizobial population. Under a low calcium régime the bacteria changes to an abnormal chromogenic form in which they are unable to invade the plant. Albrecht (1937) has even suggested that it is the low calcium content of non-legumes which determines their non-invasion.

Magnesium seems to play a closely analogous role, possibly in part because calcium is rendered more available in its presence. Nevertheless, indiscriminate liming may lead to deleterious effects where the plant shows symptoms of lime-induced chlorosis. These may be due to lower availability of other elements, notably iron, required by both plants and bacteria, and boron, which

is important in controlling the development of vascular tissue in the nodule, calcium intake and carbohydrate translocation. The boron content of legumes is very high in comparison with that of non-legumes, eight times as high according to Bertrand and Silverstein (1937). Care should be taken to discriminate in assessing the effects produced by liming between increased available calcium and reduced acidity. Although legumes have been known to grow successfully at pH 4.5, nodulation tends to be greatly reduced below pH 5.5.

Molybdenum is required in small quantities for the nitrogen-fixation process in the symbiotic system as well as in free-living nitrogen fixers such as *Azotobacter*, *Clostridium pasteurianum* and *Nostoc*. It apparently plays a specific role in the process, which can only be partially replaced by vanadium. Under conditions of molybdenum deficiency in certain leached acid soils of sloping topography, derived from ancient sedimentaries and granites in southern Australia, clover plants are yellow and stunted with poor seed production. Some degree of nodulation takes place, but there is little or no fixation of nitrogen within the nodules. The plants show symptoms of acute nitrogen deficiency, which can be relieved by treatment with either nitrogen or molybdenum. On a few soils in southern and eastern Australia, Anderson and Spencer (1949) have shown that sulphur deficiency manifests itself by similar symptoms of nitrogen deficiency. Here nodulation and fixation may proceed, but the utilization of the fixed nitrogen is inhibited in the absence of sulphur.

Artificial inoculation of legume seed

The earliest method of introducing rhizobia into fields which had not grown a particular legume before was to top-dress the new field with soil from one which had shown a good growth of that particular legume. Amounts of from one-half to 5 or 10 tons per acre were applied in this way. Alternatively, a clean seed sample was avoided and pods, burs, trash and dust from harvested seed were sown with the seed. Both these methods have undoubtedly proved effective, but they are both rather cumbersome and may introduce diseases or pests.

Laboratories of agricultural bacteriology throughout the world have obtained isolates of rhizobia of tested effective powers of nitrogen fixation, and these are distributed on a commercial scale for the inoculation of seed prior to sowing. A pure culture of the organisms is prepared on a nutrient (agar) jelly surface in a bottle, or in moist peat or organic soil. Either single strains or preferably mixtures of similar strains of rhizobia are used. For application to the seed,

the slimy growth of organisms on an agar culture is suspended in a small amount of milk or water and sprinkled over the seed so that the surface is just wet; a peat culture may be applied, dry or preferably as a thin wet suspension. Usually not more than one or two pints of suspension are necessary to treat fifty to a hundred pounds of small-seeded legumes, or a three-bushel bag of large-seeded legumes. The seed is allowed to dry somewhat, and this rapidly takes place as the seed-coat absorbs water; it is then sown in the normal fashion.

There are several precautions to be observed in handling and using inoculated seed. In the first place, a layer of living bacteria has been applied which will be killed if subjected to prolonged desiccation, exposed to direct sunlight for long periods, or subjected to severe chemical action. It is, therefore, desirable to sow inoculated seed into moist soil as soon as possible after inoculation, and certainly within a day or so. While the moistened seed is drying, it should be spread in a shady place away from the direct rays of the sun. Where fertilizer is to be applied, it should be recognized that traces of free acid, as may occur in superphosphate and sulphate of ammonia, or small quantities of copper, zinc and other trace elements rapidly destroy the root nodule bacteria present on inoculated legume seeds. The seed and fertilizer should therefore be sown separately, as is provided for in certain drills. If mixing the seed and fertilizer is unavoidable, they should come into contact only immediately before sowing and not remain together for any more than 30 minutes before entering the soil.

The use of artificial inoculation of legume seed seems warranted under almost all circumstances in which a legume is being introduced into an area where related plants on the same cross-inoculation group are not indigenous or have not established themselves as naturalized aliens. Under these conditions, an appropriate strain of *Rhizobium* may be entirely absent. Where the rhizobia are actually present, but numbers are small, a fraction of the plants may not survive sufficiently long enough to give significant yields or to set seed, and a patchy establishment results. Where nodulation is sub-optimal, the growth rate may be slow; the plant may remain in the nitrogen-hunger stage for an unduly long period, and may not emerge if adverse climatic condition or pathogenic infection should intervene during this period of great susceptibility. A pronounced rhizosphere effect is exerted by the plant on the rhizobia in the vicinity. While sub-optimal nodulation may occur initially, there will throughout the growing season be a stimulation to produce more nodules, and nodulation may ultimately be adequate by flowering or seeding time. This must inevitably be accompanied by a slower growth rate over the period of inadequate nodulation and result in reduced nitrogen fixation and total production.

Should several years elapse before the growing of a legume in a crop rotation is followed by a further sowing of that species or another legume of the same cross-inoculation group, the rhizobial population may have declined to a suboptimal level, and artificial inoculation is warranted to ensure rapid growth. In the absence of experimental evidence, it is difficult to predict all circumstances under which rhizobia may be limiting, but in general the lower the organic matter status and general fertility of the soil, the greater chance there is of such limitation. In any case, artificial inoculation is so simple and cheap in practice that its standard adoption as insurance against incomplete nodulation is justified. Typical responses to inoculation are shown in figures for field inoculation of peas and lucerne on soils of low fertility in South Australia (Strong, 1938).

	Lucerne (after 12 weeks)	Peas (after 15 weeks)
	Kg. dry matter per acre	
Inoculated	101.66	898.9
Control	24.09	104.4

Conditions of legume failure related to symbiotic nitrogen fixation

Introduced legumes may fail on account of inadequate nodulation if rhizobia are scarce or entirely absent from a particular soil type. Artificial inoculation usually provides remedial treatment except where the rhizobial population is limited by unfavourable conditions. Where this is so, treatment by applications of lime, superphosphate or organic matter may enable a greater rhizobial population to be supported. Sometimes a conditioning crop of another legume or non-legume may be used to build up organic matter along with other fertilizer dressings, e. g. superphosphate, prior to sowing a pasture legume with perennial grasses.

In some soils it may be difficult to establish a new rhizobial population if there is biological antagonism from other micro-organisms indigenous to that soil or zymogenously encouraged in the rhizosphere. Two types of antagonism have been recognized. Many soil bacteria, actinomycetes and fungi have been found to be incompatible with rhizobia, but particular emphasis has been placed upon actinomycetes producing antibiotics. Where the natural soil flora shows a predominance in this type of organism, difficulty may be experienced in establishing alien rhizobia. The second type of antagonism which has been recognized is one of the competition for sites of nodule formation by more vigorous ineffective rhizobia already indigenous in that soil. This type of antagonism has been found by Thornton and co-workers in hill pastures in Great Britain.

In either case the only possibility of success is to select a rhizobial strain capable of competing against these indigenous strains, or by modification of the soil conditions by fertilizer treatment, including liming when necessary, to render the soil more favourable for the multiplication of effective strains.

Like other bacteria, rhizobia are prone to infection by viruses, the bacteriophages. Phages capable of destroying rhizobia have been demonstrated in a number of cultures of rhizobia, nodules and in soils. Infected bacteria are killed on absorption of the phage particle and lysis of the cell contents, but in almost all populations of any one strain of *Rhizobium* some resistant cells will survive. Races of the phage are specific in their affinities for strains of rhizobia in much the same way that rhizobia have affinities for their host plants; a range from strain-specific to group-specific phages is also known. The condition of "lucerne fatigue" in France, Italy, the United States and Russia, and conditions of failure of peas in New York State and clover in Wales have been ascribed to dominance of phage in certain soils. It seems that the effect is less severe in annual crops, such as peas, beans, lupins and soyabeans, than in perennials. For remedial treatment either a phage resistant race of rhizobia must be used in artificial inoculation, or the legume crop should be temporarily abandoned in that field in favour of some other crop, preferably a non-legume. Nutritional depletion is a further factor, as yet little investigated, especially in regard to the trace elements, including their microbiological effects and relationship with the enzyme systems of the host legume-*Rhizobium* association.

Chapter Ten

PLANT INTRODUCTION AND EXPLORATION

The existing cropping pattern of the world has arisen to a great extent as a result of the progressive introduction and spread, over the centuries, of plant species into new areas. This movement may have been either what we might call adventitious, or intentional. Under the former head, we can include the gradual diffusion of a species along ancient and modern trade routes by land or sea, from one market centre to another, and from farmer to farmer. It would proceed with invasions and general migrations of populations or cultures, in the ballast of ships and the packing material or fodder of camel caravans.

In addition, there has been the intentional exploration and importation by crop introduction agencies of a new crop, or variety of a crop, or a new species of the natural vegetation from some other region or country with supposedly similar environmental conditions.

> " Efforts to introduce plants from one environment to another have been made ever since man started to cultivate plants at all. Some of the plant introductions made in the past have been astonishingly successful: for example, the Brazilian rubber tree introduced into Ceylon, Malaya and the East Indies.... the navel orange from Brazil to California. Potatoes, tomatoes and tobacco are other examples of plants introduced from South America which have now become almost universal........ Plant breeders have gradually come to see that one of the first essentials for the success of their task is to have at their disposal the greatest possible choice of types, from as great a range of geographic and climatic areas as possible, and so containing the greatest range of desirable characters that are known to exist in the plant in question.
>
> " It was this argument that led the Russian botanists in the years between the two World Wars to make a survey of the crop plants of the whole world under the leadership of the late N. I. Vavilov..... Rich and quite unexpected sources of economic plants were discovered and the range of variation within each plant was found to be much greater than had ever been previously suspected " (P.S. Hudson, 1949).

Although a certain amount of success has already been achieved in the introduction of leguminous species, the success so far achieved does not compare with that following the introduction of non-leguminous plants. The possibilities of success with the introduction of legumes have not yet been fully explored, because only recently have the particular requirements of legumes come to be understood. Insufficient attention has been given to the importance of root nodule bacteria, to inoculation with appropriate strains, or to the

soil deficiencies which must frequently be overcome to enable legumes to succeed in terms of their most important function, namely, the enrichment of naturally poor soils in available nitrogen. It will in most cases be hopeless to introduce legumes without reference to these other factors.

Centres of origin

We must in this connection refer to the theory of centres of origin of cultivated plants put forward by N. I. Vavilov. On the basis of numerous expeditions to different parts of the world, also of a detailed comparative study of a large collection of crop varieties and species assembled in the Soviet Union, Professor Vavilov concluded that it was possible to speak of eight ancient main centres from which agriculture originated, or more exactly, of eight independent regions in which various plants originated.

Below we give the centres of origin and the names of the principal leguminous genera and species believed to have their origin there (quoted from the translation made by the Commonwealth Bureau of Plant Breeding and Genetics, Cambridge, of Vol. I, Sect. II of N. I. Vavilov's book, *Theoretical Bases of Plant Breeding*).

1. Chinese Centre

The earliest and largest independent centre of agriculture and of the origin of cultivated plants consists of the mountainous regions of central and western China, together with the adjoining lowlands. The Chinese centre is conspicuous among all others for wealth of endemic species and the size of the potential of species and genera of cultivated plants.

Glycine hispida	*Vigna sinensis* subsp. *sesquipedalis*
Phaseolus angularis	*Stizolobium hassjoo*
Ph. vulgaris	

2. Indian Centre

This " Hindustan " centre of origin is second to the Chinese in importance, and nearest geographically; it includes Burma and Assam, but not north-west India and Western Pakistan (Punjab and North-west Frontier Provinces).

Cicer arietinum	*Dolichos lablab*
Cajanus indicus	*Vigna sinensis*
Phaseolus aconitifolius	*Trigonella foenum-graecum*
Ph. mungo	*Canavalia gladiata*
Ph. aureus	*D. bulbosus*
Ph. calcaratus	*Psophocarpus tetragonolobus*
Dolichos biflorus	*Cyamopsis psoralioides*

2a. Indo-Malayan Centre

This supplementary centre includes the whole Malayan archipelago, the large islands, such as Java, Borneo, Sumatra and the Philippines, and Indo-China.

Stizolobium deeringianum

3. Central Asia Centre

This occupies the smallest area, covering north-west India, Kashmir, Pakistan, Afghanistan, and, in the U.S.S.R., Tadjikistan, Uzbekistan, and Western Tian-Shan.

Cicer arietinum	*Phaseolus mungo*
Lens esculenta	*Pisum sativum*
Phaseolus aureus	*Vicia faba*

4. Near Eastern Centre

This includes the interior of Asia Minor, the whole of Trans-Caucasia, Iran and the highlands of Turkmenistan.

Cicer arietinum subsp. *pisiforme*	*Pisum sativum, Pelatius, P. humile,*
L. albus	*P. fulvum.*
Lathyrus cicera	*Trifolium resupinatum*
Lens esculenta, L. lenticula, L. nigricans, L. kotschyana, L. orientalis	*Trigonella foenum-graecum*
	Vicia ervilia
Lupinus pilosus, L. angustifolius,	*Vicia pannonica*
Medicago sativa	*Vicia sativa*
Onobrychis altissima, O. transcaucasica	*Vicia villosa* var. *perennis*

5. Mediterranean Centre

This is notable for cultivated crops of more limited significance than those recognized in the fourth centre.

Cicer arietinum	*Pisum sativum*
Ervum monanthos	*T. repens* var. *giganteum*
Hedysarum coronarium	*T. incarnatum*
Lathyrus gorgonii, L. ochrus, L. cicera,	*Trifolium alexandrinum*
Lathyrus sativus macrospermus	*Ulex europaeus*
Lens esculenta, subsp. *macrosperma*	*Vicia sativa*
Lupinus albus, L. termis, L. luteus, L. angustifolius	*Vicia ervilia*
	Vicia faba var. *major*
Ornithopus sativus	

Vavilov has stated with reference to this centre: "It is interesting to note that each civilization in this Centre introduced its own forage crops. From Egypt and Syria comes *Trifolium alexandrinum*, from the Appenines sulla and the giant white clover, from the Pyrenees the single-flowered lentil; Syria, too, was the original home of *Lathyrus gorgonii*, and Portugal of *Ulex europaeus*. Judging by the varieties and species comprising them, many of the chief crop plants point

to the existence of a secondary centre, and bear witness to the important part which man has played since ancient times in producing improved varieties ".

6. Abyssinian Centre

Ethiopia has a distinctive cultivated flora and the whole region, including the hilly country of Eritrea, undoubtedly constituted an independent centre whence some of the world's crop plants originated.

Cicer arietinum	*Lathyrus sativus*
Lens esculenta	*Vigna sinensis, V. sinensis* var. *catjang*
Pisum sativum	*Dolichos lablab*
Vicia faba	*Lupinus termis*
Trigonella foenum-graecum	

7. Southern Mexican and Central American Centre

Professor Vavilov wrote, " Here maize has played the same part as has wheat in the centres of the Old World; without it there would have been no Maya civilization. The severely restricted area of southern Mexico and Central America is full of endemic crop plants, thus differing strikingly from the vast continent of North America where agriculture, both in the past and in the present, has been and is based on crop plants introduced from outside its borders ".

Phaseolus vulgaris, Ph. multiflorus	*Ph. acutifolius* var. *latifolius*
Ph. lunatus, gr. *macrospermus,*	*Canavalia ensiformis*

8. South American Centre (Peru, Ecuador and Bolivia)

This includes the chief endemic species of the high mountainous districts, the puna and sierra.

Lupinus mutabilis
Phaseolus lunatus gr. *macrospermus,*
Ph. vulgaris

8a. The Chiloe Centre

No legumes

8b. The Brazil and Paraguay Centre

Arachis hypogaea
Phaseolus caracalla

It is believed that all these centres developed independently of each other and are autonomous, with characteristic composition of genera, species and varieties of cultivated plants, and distinctive implements, domestic animals and systems of management. All the eight centres are separated by mountain ranges; their very geography

makes for isolation and has led to the evolution of a distinctive flora and human population, which together gave rise to peculiar crop plants.

The primary areas where species of the chief crop plants were formed are very localized, occupying only about one-fortieth of the land surface of the globe. Five-sixths of all the cultivated plants originated in the Old World, and nearly two-thirds of the total arose in Southern Asia.

An interesting prospect has been revealed by J. R. Harlan who states that when domesticated species from North America are introduced into a centre of origin or rather into a centre of great specific variability, such as Asia Minor, they exhibit great variation. Some factors thought to influence this change are, (*a*) great variability of climate within short distances, (*b*) subsistence agriculture in which mixed populations of crop plants are not a drawback, (*c*) primitive or non-mechanized husbandry, (*d*) extensive type of cultivation, and (*e*) historical continuity of a society, preservation of habits, methods of husbandry, and crops.

Geographical spread of legumes

The extension of the area of cultivation of the chief leguminous crop and herbage plants has been due largely to accident rather than to the intentional introduction by specialized agencies. The following examples relate to lucerne, some clover species, the soyabean and other legumes.

According to M. Klinkowski (Commonwealth Bureau of Pastures and Field Crops, 1933), the centre of origin of lucerne is in the temperate regions of Western Asia, in and around the ancient land of Media, the south-eastern Caucasus and north-western Iran, principally steppe districts with a continental climate and soils of a high salt content.

Lucerne reached Greece about 500 B. C. and Italy 150 to 200 B. C. It spread into North Africa at about the same time, and followed the caravan trails to China. Later it reached Spain with the Moors and so out to the New World on the Spanish routes of exploration and trade, in 1500 A. D. to Mexico, Peru and Chile, and on to Argentina and Uruguay. About 1550 it was reported in France, in 1565 in Belgium, in 1580 in the Netherlands; and about 1630 in England. Then it is believed the crop spread east again to Germany, Hungary and Russia.

Lucerne probably entered the United States through California from Chile in the gold rush days of 1851-54, and through Colorado from Mexico rather later. In 1857, Grimm brought his seed of hybrid lucerne, of the Old Franconian type, from Germany to his new home in Minnesota. The crop was introduced from

France to South Africa in about 1850. Lucerne was introduced very early into Australia, was one of the first forage plants to be cultivated and received favourable comment by the Governor of New South Wales as early as 1806. Strains of the Provence type proved successful and probably led to the types known today as Hunter River, South Australian and Booborowie.

The early history of red clover cultivation in Europe was for many years characterized by setbacks. It was cultivated in Europe in the 3rd and 4th Centuries; it was grown in Spain during the 16th Century, and subsequently in Holland and Lombardy about the middle of that century. Nests of cultivation began in Germany, and from there it was taken to England in 1650 by a German doctor named Hartlieb, who settled there. It had already been described in England by Sir Richard Weston in 1645 and by Walter Blithe in 1649. It was reported in Russia in 1766.

Subterranean clover is a plant of the coastal and adjacent lowland areas of the Mediterranean lands, but there is good reason to believe that it spread out of the Mediterranean, up the coasts of Portugal and France to the southern coasts of England and Wales. In the west of Great Britain it has not been reported north of Liverpool, while on the east it is found up to the coastal areas of Norfolk. It is generally thought that this spread may have taken place from ballast and packing material in the days of the sea-borne tin trade.

None of the outstanding legumes and grasses of the northern hemisphere occurred in the natural flora of Australia, New Zealand and South Africa. So we find the great pastoral industry of New Zealand, for example, based primarily on white and red clovers and their companion grasses, introduced by the early settlers from their home countries of northern Europe. There are now two million acres sown to subterranean clover and its companion grasses in the Southern parts of Australia, where this species has acquired an economic significance far exceeding that in its native habitats in the Mediterranean.

It is not known how subterranean clover reached Australia, but the strains which have now been discovered entered as accidental introductions, either from the Mediterranean region where many different types of this species occur, or from the south of England, where, as already noted, it occurs in proximity to the ports from which ships have most frequently departed for Australia. For many years, the Mount Barker strain was the only one known. This was discovered by A. W. Howard in the Mount Barker district of South Australia near the end of the 19th Century and was first commercialized by Howard in 1906. Other strains were recognized in Western Australia in the 1920's and were commented on by Sir George Stapledon during his visit to Australia in 1926. The West Australian strains were grown at the Waite Agricultural Research Institute in 1929 and

subsequent work in both Victoria and South Australia led to the recognition of the numerous strains which are now available. Some half-dozen have now been introduced into commerce, namely Mount Barker, Dwalganup, Tallarook, Bacchus Marsh, Yarloop and Clare, of which the most important are Mount Barker and Bacchus Marsh. Presumably new types of more recent Mediterranean origin will become available as a result of the extensive collection made by C. M. Donald and J. F. Miles of C. S. I. R. O., Australia, in the Mediterranean countries in 1951.

The naturally occurring species of *Trifolium* in the United States are of little use for herbage or soil improvement crops, and the great development in the forage resources of that country has been due to the accidental introduction of red and white clovers, in addition to lucerne and the numerous other legumes of American agriculture. White clover in particular has now become fully naturalized in the regions to which it is adapted, and the great current development is associated with the Ladino types originally introduced from Italy early in this century.

Plant introduction

Controlled, as distinct from adventitious, introduction of new species or varieties, is done by government agencies, universities, private individuals, or the seed trade, by obtaining seeds which may already be on the market in other lands, or by sending special expeditions to explore the resources of the natural vegetation in regions of similar climate. This is rather distinct from the routine importation of seed in the course of normal trade. Conditions in Great Britain, for example, are unfavourable for producing seed of lucerne, and the greater part of the country's seed requirements are met by importation from France or North America; Sweden and Denmark are in the same position and import their lucerne seed from the same sources. Introduction of commercial material entails bringing in seeds of promising strains, testing them in the usual way, and arranging for their multiplication if found suitable; it may be necessary to carry out some selection or breeding work before this final stage is reached.

When considering the exploration of natural vegetation for new types of herbage plants, the question frequently arises as to whether one should expect better results from the indigenous flora of the country concerned or from that of other lands. This is a question which depends so much on local conditions and requirements that it is impossible to make any generalized statement. Each country or authority has to assess the possibilities for itself and proceed accordingly. Mediterranean countries with a rich store

of indigenous legumes might be expected to gain as much if not more from local exploration, and southern Australia more from introductions from other lands with a flora richer in natural legumes.

One vital omission in the introduction of new legumes which has led to failure and unwarranted conclusions as to the non-adaptability of a species is in connection with the root nodule bacteria. In the case of subterranean clover in southern Australia, it was a fortunate accident that appropriate root nodule bacteria were inevitably carried with the seeds, since these are usually formed in close contact with soil containing these bacteria. Other legumes, which produce seeds in pods with no chance of contact between seeds and soil, may be introduced without the necessary root nodule bacteria accompanying them. In addition, it was only when available phosphate came to be applied with the clover that its value became apparent in southern Australia. This occurred from about 1921 onwards; for two or three decades previously, the clover was recognized as of possible value, but the comparatively poor growth made in the absence of soluble phosphate gave no indication of its real potentialities. One must, therefore, always stress the need to arrange to cover inoculation requirements, and to correct deficiencies in soil nutrients, not only of phosphate but also calcium, sulphur, potassium, boron, copper, zinc, molybdenum, and even magnesium, manganese and iron.

It is not essential that an introduced strain should always be initially adapted to a new country, since to the plant breeder an ill-adapted introduction may possess some characteristics of special value which, by crossing with a native strain followed by selection, may be a fruitful means of improving the native strain. Further, it is necessary when introducing a new strain to have full information of the altitude and more especially the latitude of its place of origin.

Climatic correlations

It would be of great value to plant explorers if they could be provided with some reasonably accurate criteria whereby they might compare and correlate climates. Unfortunately, the classifications of those geographers who have specialized in this field do not yet appear to meet the need. The schemes and criteria of Köppen and Thornthwaite do not seem applicable except in a general way as indicating the extent of macro-divisions such as winter rainfall, summer rainfall, and so on. Nor do Nuttonson's agro-climatic analogues really provide the full data required in planning and carrying out plant introduction and exploration. It appears that so many factors govern the adaptation of a plant to an environment that it is very difficult if not impossible to express them in mathematical formulae.

Successful introductions

In elaboration of the foregoing discussion, we will now give some examples of how plant introduction and exploration have contributed to an extension of the cultivation of legumes. In some cases the authorities concerned have looked to other lands for their material, in others they have restricted their activities primarily to their own country.

Lucerne reached the United States through Chile and Colorado, while the hardy northern types came into Minnesota. Since these early days, the plant introduction authorities in the United States Department of Agriculture have introduced a great many types, and special expeditions, such as that of Westover and Enlow, have gone in search of new types in Turkestan and elsewhere. But perhaps the outstanding leguminous plant introduced into the United States is the soyabean.

Originally cultivated extensively in Manchuria, soyabeans were probably brought into the United States from China and Japan as early as the Colonial period, but serious investigations did not begin until about 1890. The United States Department of Agriculture introduced a number of varieties in 1898, and by 1910 about 50,000 acres were under cultivation.

Success with some of the varieties and the eagerness with which growers accepted the new plant immigrant caused an early demand for types adaptable throughout the central states. Plant explorers combed the soyabean areas of northern China, Manchuria and Japan from 1929 to 1931, bringing hundreds of forms to the United States. Many of these soon found their way into commercial cultivation. Worth 13 million dollars in 1929, the soyabean industry by 1944 increased in value to 395 million dollars. This spectacular development would not have been possible without the patient, fundamental exploration and introduction which preceded it (R. McKee, 1948).

The original introductions were from Manchuria, but a later expedition by W. J. Morse of the United States Department of Agriculture to areas south of Manchuria led to the introduction of short-day types from these latitudes. There are now seven soyabean nurseries in the United States and the crop area has been extended to the Gulf of Mexico. Louisiana is now an important state for this crop and the variety Pelican is a well-adapted short-day type.

Attempts to introduce the soyabean into South Africa during the last 50 years or more largely failed because the varieties tried shattered their seeds at maturity. The crop was also found to be very particular in its cultural requirements; this and the lack of any price incentive did not increase it in the farmers' favour. Since World War II, however, the situation has radically changed, according to Dr. A. R. Saunders. The problem of shattering had

been overcome before the war by the breeding of non-shattering strains, and the cutting off of supplies from the Orient has led to price increases to a level competitive with other crops. Soyabeans, therefore, seem likely to achieve a prominent position among South African crops in the next 20 years. The crop is grown both for forage and seed.

Lespedeza is an example of a wild plant in the early stages of domestication. The genus is composed of both shrubs and herbs. As far as is known only two of the species are annuals, and these, introduced from Asia into the United States, have revolutionized agriculture over some 20 million acres of lime-deficient, sandy land in the southern and eastern parts of the country. The annual types are Common and Korean, the perennial Sericea. Common had become established in fields and roadsides of Georgia by 1850, and commercial seed was available in the early 1900's. Korean was introduced in 1919, Sericea from 1896 onwards. Although many other countries have been interested in the American success with *Lespedeza*, they have been unable to repeat that precise combination of conditions apparently required for its success.

The authorities in Australia are also greatly interested in plant introduction, more especially of herbage plants since so few occur naturally in the vegetation. A special Division of C. S. I. R. O. is concerned with this work. In addition to the routine work of plant introduction by correspondence and personal contacts, the Australian authorities collaborated directly in an American expedition to the summer rainfall areas in South America in 1947/8; in 1951, they sent two of their officers to collect in the Mediterranean area.

The Grassland Survey Group sent by O.E.E.C. to survey the fodder resources of the Mediterranean lands in the spring of 1951 recommended that each country should explore the resources for new types of herbage plants which exist in their indigenous flora, and that they should also introduce proved material from other winter rainfall environments, such as southern Australia and other areas of comparable latitude.

Local introductions

A number of countries have relied on the indigenous and naturalized herbage plants in their own pasture lands to provide the basic material for the breeding of new and improved strains. In Great Britain, for example, since one of the primary objectives was the production of pasture strains capable of herbage production under long and intensive grazing, the plant breeders from Aberystwyth and Corstorphine collected their basic material from permanent pastures which had received just this type of treatment.

The Swedish plant breeders have, with few exceptions, relied on their natural resources to provide new leguminous material. The

wide range of climatic and soil conditions throughout the country has provided a wealth of material so far as red clover and alsike are concerned. In order at the same time to meet the demand for improved strains from farmers in this same wide range of conditions, the breeders have to produce an equivalent variation in any improved material they have to offer. They have, therefore, concentrated on the collection and improvement by selection of the leading local races, and on crosses between these races to combine desirable characters. A recent important development has been the research into the production of tetraploid strains of red clover and alsike by chromosome doubling; this has already led to the appearance on the market of a tetraploid strain of alsike. The situation is rather different in white clover. Here the above technique is combined with introductions from Denmark and New Zealand. A new strain is in course of production at Svalöf based on the New Zealand material, but without the undesirable tendency to commence active growth during short, favourable periods in winter. So the New World is already giving back to the Old World.

It is in this connection desirable to indicate what is meant here by "indigenous" and "naturalized", since these terms do not always have the same connotation. White clover is indigenous in Great Britain and Sweden, being a component of the original ground vegetation in the forest glades and fringes; in leaving the forest shade for the open meadow it may have changed its genotype or ecology to some extent. Although there is in Sweden, and possibly also in Great Britain, an indigenous type of red clover, *Trifolium pratense*, very early, prostrate, with few leaves, and many flowers, most if not all of the commercial and bred strains originate from material introduced from elsewhere many years ago which has since become naturalized. Prianishnikov in Russia believes that the indigenous type of *Trifolium pratense* has played a part in the constitution of Russian strains of red clover, but the wide difference in flowering times makes crossing somewhat unlikely.

White clover in North America or New Zealand is a typical "naturalized" species; it was previously not in the natural flora of these countries, but it has, since its introduction from Great Britain or western Europe, become equivalent to a wild species and spreads by self-seeding.

Plant introduction in the United States

The introduction of plant materials from foreign countries was one of the first agricultural activities of the federal government. As early as 1819 a circular from the Secretary of the Treasury went to all representatives of the consular service, urging the sending home of important plant materials discovered in foreign countries. In 1839, an appropriation of one thousand dollars was granted by

Congress for the collection and dissemination of agricultural seeds and plants, to be carried out by the Commissioner of Patents (C. O. Erlanson, 1952).

By 1898 it was recognized generally that formal procedure was needed to handle the introduction of new plant material. Seeds and plants brought from abroad by travellers, missionaries, explorers, and immigrants were often valuable but seldom received adequate trial under proper conditions. No centralized record was available as to the results of trials. Foreign diseases came in and threatened the crops. Also, the development of the science of plant breeding caused a great impetus to the demand for specific programmes of introduction.

Within the Federal Department of Agriculture a unit was organised, now called the Division of Plant Exploration and Introduction, to centralize plant introduction activities, a step which has since been taken in many other countries. Such centralization in no way precludes the free exchange of materials among nations, individuals, institutions or states, but is designed to implement and safeguard such exchange with expert services and knowledge gained by cumulative experience. It handles the needs of vast regions as well as local problems. Since this unit was established, 200,000 plant introductions have been noted and their subsequent history recorded.

Foreign plant material is obtained in various ways. A continuous and active exchange with foreign research workers and institutions brings in the greater amount. Direct purchases from seedsmen and nurseries account for additional strains and varieties of cultivated materials. Potentially, the most important and the hardest to obtain are the foreign wild plants, which are related to the important American crops and may have characteristics needed to extend their adaptability and vigour, or which in themselves may become new crops. The procurement of such material usually requires specially planned exploration.

Each introduction by the federal workers is given a serial number. With the number is recorded all information that came with the plant as to source, collector, and possible value. The introduction passes through sanitary inspection, is fumigated or otherwise treated when necessary, or is grown under quarantine. Botanists verify its identity as closely as the material will allow; then the introduction may be ordered out for propagation and trial.

The material obtained deliberately for use in active breeding and improvement work is immediately turned over to research workers. With the constant inflow of introductions, however, come valuable seeds and plants which are of no immediate interest in any work, but which should be propagated and investigated to ascertain their future usefulness for the United States. For this purpose, the Federal Government maintains four Plant Introduction

Gardens in Maryland, Georgia, Florida and California. They are supplemented by various state and federal experimental stations that maintain special collections. The maintenance and testing of these reservoirs of germ-plasm material are limited by funds available, but these activities have proved so valuable that recently new regional stations have been established which are operated co-operatively between the state agricultural experimental stations and the federal government to investigate better the plant introductions constantly coming into the country through federal activities.

One of the basic problems of plant introduction is the procurement of plants which may be used to diversify the agriculture of the several regions of the United States. A dependence on the one or two crops found to be most successful in a region often leads to trouble in a period of abnormal drought, pestilence, or overproduction. In diversification there is stability.

Plant introduction in Australia (*C. S. I. R. O.*)

Almost immediately after the establishment of the Division of Plant Industry (then the Division of Economic Botany) in 1928, a Plant Introduction Section was formed to rationalize the introduction and testing of plants for all parts of Australia. While in the early days large collections of cereal varieties were introduced for genetic study, the introduction and testing of pasture plants, and especially pasture legumes, has always been a major activity of the Section. This is due to the great dependence of Australia on pastoral production, and to the conspicuous success of some exotic pasture legumes - notably subterranean clover and annual species of *Medicago* - in the more temperate parts of the continent. The introduction and establishment of these species had been due almost entirely to chance, and it appeared reasonable to hope that better biotypes might be obtained through planned introduction. Further, it was considered possible to obtain suitable pasture legumes for the tropical and sub-tropical parts of the continent in which the low protein content of the native pastures in winter and spring limits the production of both cattle and sheep (W. Hartley, 1952).

The Section has introduced upwards of 16,000 varieties of plants, including about 8,000 actual or potential pasture plants, these being roughly equally divided between grasses and legumes. They have been obtained from all parts of the world, with special emphasis on those regions similar climatically to one or other of the great pasture zones of Australia. Until recent years, introduction has been conducted entirely by correspondence, with the inevitable result that the less developed regions could not be fully tapped,

and with the probability that the strains of any species obtained were not always those most valuable as pasture plants.

Recently it has been possible to supplement correspondence by organised exploration. Collections were made in eastern South America in 1947/48, the countries visited including Argentina, Uruguay, Paraguay and southern Brazil. Particular attention was given to species of *Stylosanthes*, *Desmodium* and *Arachis* as previous trials had shown the value of these genera in coastal Queensland. In 1951, two officers collected extensively in the Mediterranean region, obtaining more than 1,400 varieties of pasture and other plants, with special emphasis on ecotypes of subterranean clover and *Phalaris*. One of the officers continued through north, central and south Africa, and sent back a host of potentially valuable tropical pasture legumes, as well as tropical and temperate grasses. The great variety of interesting material obtained in these expeditions, much of which is unrecorded in the literature, serves to emphasize the importance of plant exploration in the future work of the Section.

Organisation. At the present time the Section consists of a central unit at Canberra, with field stations in widely separated parts of the Commonwealth.

The central unit comprises a plant geographer and quarantine officer, in addition to the officer-in-charge and records staff. It is responsible for the introduction and exchange of material both within Australia and overseas, for the maintenance of full records of all introductions, for quarantine inspection and treatment of incoming and outgoing seeds and plants, for the allocation of material for agronomic trial, and for some aspects of the more fundamental work referred to below.

Field stations are established at Canberra in conjunction with the central unit, also at Brisbane (Queensland), Katherine (Northern Territory) and Perth (Western Australia). These stations include quarantine nurseries, in which all new introductions are grown initially under close inspection, and trial grounds in which the more promising plants can be further tested. The selection and location of these stations, each in one of the major climatic zones of Australia, are based on experience tending to show that it is possible, on the basis of preliminary trials at one or more stations, supplemented by information on the natural distribution and overseas performance of the plants, to allocate introductions with some confidence to the sub-regions in which they are most likely to be of value. Thus, preliminary trials at Canberra make it possible to select plants meriting trial at a more arid station in New South Wales, such as Deniliquin, but the reverse procedure would rarely be practicable.

Each field station is staffed by one or more research or technical officers, and is responsible for the " sorting out " of new introductions for the region which it serves. As these regions are themselves very large and include a great diversity of climatic and edaphic conditions, the final evaluation of the plants must be based on trials at sub-stations within the region. Such sub-stations may be centres at which C. S. I. R. O. is itself established or may be experimental stations controlled by the State Departments of Agriculture or the universities. Rarely are they located on the properties of private farmers or graziers. Contact with the trials at such centres is maintained through frequent visits by the plant introduction officer concerned, and every effort is made to obtain the co-operation of all those willing and technically competent to assist in the evaluation of new introductions.

Evaluation Procedure. The methods used in assessing new introductions naturally vary with the nature of the plants concerned, and, in particular, there are broad differences in the treatment of crop and pasture plants. The following notes apply particularly to pasture plants.

All new pasture plants received are normally grown in rows in a quarantine nursery for periods of up to 3 years, with four main objectives:

1. to ensure that the plants are free from diseases and pests, and are unlikely to become serious weeds;
2. to build up seed supplies for more extensive trials;
3. to eliminate those plants which, because of low productivity or other reasons, are not considered to warrant further trial; and
4. to obtain information about the seasonal growth rhythm of the plants, and thereby assist in allocating them for further trial at sub-stations.

Objectives 3 and 4 are facilitated by including check rows of standard pasture species at frequent intervals in the trial nursery, and by making a visual productivity rating of all introductions against the controls regularly throughout the season. While recognising the dangers inherent in assessing pasture plants under row conditions, it is exceptional for such assessments, made by trained observers, to contrast sharply with the performance of the plants in swards.

Following these initial nursery or elimination trials, the more promising introductions are increased in seed multiplication rows. At the same time an attempt is made to obtain more quantitative information about the seasonal and total productivity of the plants by making regular herbage cuts and recording the dry weights obtained. These cuts also give some indication, *ceteris paribus*, of the probable ability of the plants to withstand heavy grazing, while

chemical analyses of the dried material are useful in assessing their nutritive values.

The results of these multiplication row trials lead to a further elimination of species which are unable to persist under frequent clipping, or which have a low nutritive value. The survivors are sent for trial at those sub-stations to which they appear to be best adapted, as judged by their performance at the primary centre, and are further tested in plots, using either a clipping or grazing technique. These replicated plot trials naturally vary greatly according to the material involved, but generally new legumes are tested in simple mixtures with standard grasses, and *vice versa.*

Modifications are constantly made in this general procedure in accordance with the current trends of thought in Australia and abroad. Thus, recent work has emphasized the importance of nutrition, including the availability of major and minor nutrients, in the establishment and productivity of Australian pastures. The performance of an introduction under one level of nutrition may give little indication of its potentialities at a higher or lower level. To assist in overcoming this difficulty the more promising introductions are being increasingly tested under two or three levels of nutrition, and care is taken to remove any known trace element deficiencies.

Closely related to the nutrition problem is that of ensuring that pasture legumes are adequately nodulated, particularly when the species under trial are of little-known genera from underdeveloped parts of the world. As opportunity permits a culture collection is being built up, and new legume plantings are inoculated whenever the need is apparent.

While emphasis has been placed upon productivity ratings as a basis for evaluation, it is recognized that in many regions, especially of the tropics and sub-tropics, over-all productivity is of less importance than the ability to retain a high nutritive value during the unfavourable period of the year. Chemical analyses are made at an early stage in the evaluation, while close contact with regional agrostologists helps to ensure that the less obvious potentialities of new species are not overlooked.

Basic Research. Reference is made above to the need for some reasonably accurate criteria for the comparison and correlation of climates. Most of the existing climatic classifications, such as those of Köppen and Thornthwaite, have as their ultimate basis the distribution of vegetation rather than of the species or biotypes which form the significant units in plant introduction. There is need for a re-assessment if climatic data in relation to plant distribution are to be used other than as a general guide to the areas in which exotic plant should be tested.

At Canberra, a modest start has been made on such studies by utilizing floristic data to provide a measure of comparability

between widely separated regions, and relating this measure to indices based on climatic data. It is proposed to extend this work, also to make use of all other available indices of plant distribution, such as Raunkiaer's lifeform spectra and data obtained from the study of the distribution of weeds and other naturalized plants. At the same time a detailed, comparative, phenological study is being made of the performance at selected stations in Australia of several ecotypes of each of a number of species, the origin of which is precisely known. It is hoped to ascertain whether, and in what way, the performance of these ecotypes in Australia can be related to the climatic and other environmental conditions of their places of origin.

While it is recognized that the physiological requirements, and hence the environmental limits, of every species, and indeed of every ecotype, will have individual peculiarities, it is hoped that, by studies of the kind indicated above, it will be possible to define more exactly those areas in widely-separated regions which are most closely comparable from the viewpoint of plant environment. This is necessarily a long-term objective, but any success would be of value not only for plant introduction, but also for related studies, such as those on weed distribution. The results would also help to throw light on those climatic factors of primary importance in plant distribution.

A more immediate objective has been the preparation of climatic maps for introduction work in selected regions or for selected groups of plants. As instances of this, maps have been prepared of the agricultural and pastoral growing season in Queensland and other parts of northern Australia. Such maps are of value both as indicating the possibility of establishing annual or perennial exotic pasture plants and in the selection of crop varieties of suitable growth period.

While this review of the work by C. S. I. R. O., Australia, has been concerned rather with the techniques involved in testing introduced pasture plants than with the results obtained, brief reference may be made to some of the legumes which have shown outstanding promise.

In the spear grass (*Heteropogon contortus*) pastures of Queensland and northern Australia, the need for suitable pasture legumes is particularly acute. These pastures are of great importance for beef production, but their nutritive value falls to a very low level in the winter and spring months, and stock are unable to maintain condition. A perennial legume from South America, stylo (*Stylosanthes gracilis*), is of particular value in these pastures as it is readily established, well grazed during the dry winter months, and although of poor nutritive value in comparison with the better temperate legumes, such as lucerne, much superior in this respect to the dried-up grasses. The final evaluation of this species is dependent upon

controlled grazing trials which have not yet been completed, but in the meantime seed has been sent to other tropical and sub-tropical countries and it has become well established and is highly regarded in Fiji, Ceylon and elsewhere.

Varieties of pigeon pea (*Cajanus cajan* var. *bicolor*) from India have been grown very successfully in coastal Queensland, and suggest an alternative solution of the problem of protein deficiency through the production of a protein-rich grain supplement. There are unsolved problems of mechanical harvesting in this crop, but beef cattle readily strip the standing plants of leaves and pods.

On the heavier soils with good rainfall, species of *Desmodium* from South America, especially *D. uncinatum* and *D. canum*, make excellent growth. These perennial legumes are of great importance as pasture plants in their countries of origin also in Hawaii where they have become well established. In Australia, they await critical comparison with the naturalized annual, *Phaseolus lathyroides*, which thrives under similar conditions and has a high nutritive value.

Another genus of particular interest is *Arachis*, the wild perennial species of which include types with rhizomatous and stoloniferous growth habit, and which should be ideal pasture legumes for the tropical and sub-tropical regions. All, unfortunately, set seed very sparsely, and their full utilization is dependent upon ensuring good seed production. This is under investigation from the genetic and nutritional aspects.

In the irrigation districts of south-eastern Australia, the annual legume, *Lathyrus ochrus*, introduced from Israel, outyields, and may replace, tick beans as a green manure and cover crop in vineyards and orchards. It is particularly valuable on very light, sandy soils. In Western Australia, several species and varieties of vetch (*Vicia*) are promising as grain legumes, to replace field peas, which suffer severely from insect pests. Varieties of *Vicia articulata*, introduced from Louisiana, have been outstanding and appear to be ideally adapted to a climatic zone, superficially very different from that whence they were obtained.

These examples serve to indicate the possibilities of successful plant introduction and the attendant difficulties. There is a wealth of valuable material still awaiting discovery and exploitation, especially in regions which are very distinct floristically from those in which the plants are to be utilized. Thus, perennial *Arachis* species are almost unknown outside South America, and little information about them is obtainable from published literature. On the other hand, the full evaluation of introduced pasture and forage legumes is, at best, a lengthy and difficult task, very insecurely based on the present methods of climatic comparison. For full success, plant exploration and agronomic testing must be supplemented by basic research in plant geography.

Chapter Eleven

ADAPTATION, STRAIN VARIATION AND BREEDING

Adaptation

It is well known that individual species have very different requirements of light and temperature for their optimal development. Whereas most species prefer direct sunlight, others are found only in the woods and the deep shade of big trees.

Nearly all cover and green manure plants thrive well and develop normally in direct sunlight, but some can be successfully grown in shade. Thus, *Centrosema pubescens* is difficult to start in shade, but grows quite well under such conditions when once established. It may, therefore, be sown, for example, in young rubber plantations and will continue to grow when the shade of the trees becomes more dense. *Tephrosia candida* and *Calopogonium mucunoides* only endure partial shade and cannot be grown under big trees, whereas *Desmodium gyroides*, *Pueraria phaseoloides* and *Vigna hosei* thrive quite well under dense shade.

Every species needs a minimum amount of heat for completing its development, and this need is much smaller in plants indigenous in cooler regions than in the sub-tropical and tropical plants. The requirements for both temperature and light also vary widely at different growth stages. Whereas the early growth stages of autumn or spring-sown crops in temperate climates require only comparatively low temperatures and low light intensities, the flowering and fruiting of the same crops need much more heat and light. In an unshaded locality the intensity of light and the temperature are both usually higher and the moisture lower than in a shaded locality nearby. The reason why some plants prefer one place to another may therefore, in some cases, be light, in others, temperature or moisture conditions, or a combination of all three.

It is not only the intensity of the light which influences the development of plants. In the last few decades, investigations have been made which show that species and varieties react very differently to the duration of daylight, especially in the development of the reproductive organs. Whereas some plants, the so-called "short-day" plants, are able to complete their development, flower and set seed only in regions of comparatively short days (most sub-tropical and tropical plants), others, the "long-day" plants, need comparatively long days for the same purpose. Other plants are

more or less indifferent in this respect. These differences in reaction apply in some cases to whole genera, in others to species; even individual strains or varieties within a species may react differently. The soyabean (*Glycine max*) is usually considered to be a short-day plant, which will not seed freely in high latitudes. Since, however, plant explorers and plant breeders have produced strains which are comparatively neutral to length of day, it has been possible to move the limit for soyabean growing in Europe and North America quite considerably northwards. Pereverzev, in the U.S.S.R., (1940) Overholt in China (1949) have shown thats unn hemp (*Crotalaria juncea*), a typical short-day plant, has a scanty seed yield when grown under long-day conditions, but develops more vigorously vegetatively—a great advantage in a green manure plant. The velvet bean (*Stizolobium deeringianum*) is on short photo-periods a bushy plant but becomes twining on long photo-periods, while the effect is reversed in the jackbean (*Canavalia ensiformis*). *Lespedezas* are short-day plants. When grown in Hawaii (day-length less than 14 hours) they seem to seed directly and become too stemmy to be of any value as forage plants. This is, however, not the case in the corn belt of the United States where they behave as leafy and valuable fodder plants (Nakata, 1952). There are many more complications to this problem, such as the influence of increasing or decreasing length of day upon various stages of the plant metabolism. In higher latitudes evidently also the absolute quantity of light is often a limiting factor to the production of common hay and pasture legumes.

Many winter annuals or biennials need a period of cold weather to induce the development of reproductive organs. Thus, when sown late in spring, sweet clover strains of northern origin do not develop any flowers in the same year, whereas inflorescences are abundant after the cold of the winter. Other plant species (peas, vetches, lupins) need only a comparatively cool climate; in regions of severe winters and cool summers they are grown as summer annuals and in regions of mild winters and hot summers as winter annuals.

Purple lucerne (*Medicago sativa* and *M. varia*) is mostly grown in temperate climates. For forage production it can be cultivated both in rather dry and rather humid regions provided the soil is well drained. For economical seed production a rather dry and warm climate is needed. This plant is, however, also to a great extent and with very great advantage grown under irrigation in hot and arid climates and, with or without irrigation, even in the dry tropics. If the water supply is sufficient it stands dry heat quite well, but a combination of heat and high air moisture is detrimental. Although admittedly different strains of lucerne are grown in the severe winters and cool summers of Canada, Northern Europe and Northern Asia on the one hand, and in the mild winters and hot summers of sub-tropical and tropical regions on the other, this example shows that there are certain limitations to the adaptation of a species

and that these limitations often depend upon a combination of several factors, in this case temperature and moisture.

Generally, lucerne is considered to be a drought resistant plant. Its drought resistance does not depend upon the fact that it is economical with the water supply. On the contrary, it is one of the most wasteful forage plants as far as water is concerned. Lucerne needs 750 tons of water to build up 1 ton of cured hay; i. e. a ton of cured lucerne will require between 7 and 8 acre/inches of water. In the arid regions of the United States, the ground water level has sunk considerably when lucerne has been grown continuously for a sequence of years. The drought resistance of the lucerne must consequently have another cause, namely, that its roots penetrate the soil whenever possible to a very considerable depth and reach the ground water. It is, therefore, not surprising that this species does not suffer from the shorter drought periods in which the more shallow-rooted clovers, for example, succumb. South Australian experience has shown that lucerne will survive for some years in the absence of free ground water; available moisture at depths in the subsoil may keep it alive for some considerable time. There is a drought endurance factor in addition to capacity to explore the subsoil for available moisture.

Drought resistance as opposed to drought escape is largely aided by deep root penetration and a physiological capacity to endure desiccation of the tissues. Mechanisms for economizing with water are the maintenance of comparatively high osmotic pressure in plants adapted to dry conditions, the reduction of the evaporating area of the leaves during especially exacting conditions, etc. The latter may be attained by throwing off the foliage, partially or completely, during the dry season, as occurs, for example, in *Desmodium adscendens*, *Indigofera endecaphylla* and certain varieties of *Vigna sinensis*.

The annual species of *Medicago* (bur clovers) and *Trifolium* (hop clovers, subterranean clover and others) for the most part escape drought, and there is a close relationship between their normal period of growth and the period over which moisture is available in the surface soil. These species are characterized by a fairly high proportion of hard seeds; this enables them to tide over the season in which the stand may be lost through failure to produce seed owing to an early drought before growth and seed production are complete.

Procumbent and creeping plants which cover the soil by a layer of foliage, e. g. species of *Calopogonium*, *Desmodium*, *Dolichos*, *Indigofera*, *Pueraria*, *Shuteria*, *Stizolobium*, *Vicia* and *Vigna*, help to keep the temperature down by shading the soil and reducing direct evaporation from it. When they do not themselves consume too much water, they may be of great importance in adjusting the soil conditions for the growth of associate crops.

Leguminous plants are found in nearly all parts of the world where higher plants are able to live. We find them growing wild

on the arctic tundra and in high altitudes at the margin of the everlasting snow and glaciers, yet they are also abundant in the tropics and at sea level. There is, consequently, no doubt that a very great adaptation to different temperature conditions exists within this family, also within certain of its genera. For example, species of *Astragalus* are found in Iceland and Greenland, as well as in the tropics. There is also a very great range of adaptation within certain species. It might be said that generally those species which are notable for their long period of cultivation and use by the human race are also characterized by extremely wide geographical range, accompanied by great diversity of ecological types. Field pea (*Pisum sativum* subsp. *arvense*) and common vetch (*Vicia sativa*) are successfully grown north of the Arctic circle in Scandinavia but are also cultivated in the tropics in India. It is not, however, the same strain of these species which is grown in these extremes of climate. Other crop plants of very wide distribution are lucerne (*Medicago sativa*) and red clover (*Trifolium pratense*). But it is a well-known fact that the range of adaptation of each individual strain of these species is rather limited, and that strains grown in northern Europe, Siberia or Canada are very inferior when grown at the Mexican Gulf, in the Mediterranean area or in tropical Asia, and *vice versa*.

These delimitations depend not only upon different adaptations to temperature conditions but upon pure frost resistance. Many other factors, such as length of daylight, resistance to drought, to prevalent plant diseases and animal pests are just as important. Even the character commonly called winter hardiness in sub-arctic climates is a very complex one, comprising not only pure frost resistance, but also resistance to heaving and to prevailing fungous diseases (*Fusarium*, *Sclerotinia*, etc.) favoured by the cold and moist climate. Plants which start vegetative growth in a short spell of mild weather during the winter lose their frost resistance and will be killed in a following cold period, whereas types having a deep winter dormancy will remain in the bud stage and come through the winter untouched by the frost. In warmer climates, winter hardiness, apart from a certain fundamental tolerance to occasional frosts or low temperatures and growth stage, consists to a great extent of disease resistance.

Breeding for adaptation and disease resistance

There is a great need for extensive breeding in many winter annual, biennial and perennial leguminous crops with the object of adjusting the strains now existing to the various hardships of the cooler season. With reference to the wide range of adaptation to winter conditions existing within the group, it might be said that

chances of speedy results from such work are very good. Inter-and intra-specific crosses, selection after refrigeration and artificial disease epidemics will be the main ways of reaching this goal. The basis of such work will, however, be the collecting and testing of material of wild and cultivated types from climatically suitable areas.

Just as there is a need for adaptation to low temperatures and conditions caused by them in the temperate and sub-arctic regions, so is there a need for adaptation to high temperatures and higher humidities in the tropics. Some aspects of these problems have already been touched upon, and very often the main factors influencing growth in these regions are excessive drought or excessive moisture. Generally, it can be stated that there are few leguminous forage or soil improvement plants adapted to such conditions. Where regulated irrigation and drainage cannot be supplied in such regions, very few legumes are now grown. In all probability, however, suitable plants already exist, and only require to be found and worked upon.

Many fungal, virus and bacterial diseases as well as insects and other animal pests attack the legumes and are often detrimental to them. Such attacks are favoured or checked by environmental factors specific to each organism. Man has also devised many remedies for their control, such as dusting or spraying with chemicals, special rotations avoiding frequent return of susceptible crops, etc. The cheapest remedy is, however, in most cases to develop resistant varieties wherever possible. In co-operation with phytopathologists and entomologists who can produce artificial epidemics and expose their material to them, the breeders of legumes in the last few decades have been able to select an ever-increasing number of strains of the economically important legumes with a lower or higher degree of resistance towards one or more devastating pests.

So far breeding for disease resistance has been most successful in North America. In no other part of the world has such active attention been given to this line of plant breeding. The reasons are obvious. Climatic conditions of North America are in many cases especially favourable to particular diseases or to their spreading over vast areas, and in North American agriculture great emphasis is placed on cultivated legumes grown as field crops and forage crops. Much still requires to be done, however, even in the United States and Canada, in breeding for resistance, and the work is complicated by the steady appearance of new biological forms of the disease-carrying organisms. It is, therefore, a work which will have to be continued for all time. In new work on legumes in any country the possibility of future diseases should be borne in mind from the outset in all testing and breeding programmes.

Just as disease resistant strains have been produced by artificial epidemics and selection, plant breeders everywhere have tried to

adjust the cultivated legumes to other influencing factors, such as light, temperature, moisture, etc.

In leguminous plants, as in plants of other families, there exist great variability in all characteristics. This variability is caused to a great extent by crossing different existing types within the individual species, but also in some cases by crossing more or less related species (e.g. crosses between *Medicago sativa* and *M. falcata*, resulting in the "variegated" lucernes). According to the mode of pollination, there are three major groups, namely, those which are:

(*a*) normally cross-pollinated and tend to be largely self-sterile, as red and white clover (*Trifolium pratense* and *T. repens*);

(*b*) usually cross-pollinated but can be readily selfed, as lucerne (*Medicago sativa*); and

(*c*) invariably self-fertilized and are in effect only cross-pollinated with a certain amount of trouble, e. g. subterranean clover (*Trifolium subterraneum*) and many annual medicks (*Medicago* spp.)

Crosses occur spontaneously, especially in the regularly cross-fertilizing species, whereas they are naturally less frequent in those which are normally self-fertilized. For the purpose of breeding they can, however, generally be made in the latter group. Variation is also brought about by means of mutations; these are sudden changes in the genetical composition of the organisms, the cause and behaviour of which are so far only partially known.

By means of natural selection, geographical or genetical barriers, the influence of human factors on the development of regional types and many other factors, one can build up innumerable strains differing widely in character. Many of these possess valuable agricultural characteristics, such as resistance to drought, pests or diseases, high-yielding capacity, high protein content, etc.

Mass selection

The improvement of leguminous plants started in all species with the isolation, testing, conservation and multiplication of naturally formed strains of more or less stable composition. In the beginning great progress could be achieved in this simple way. Well-known examples of such breeding are the local strains of red clover in central and northern European countries; the hardy, common and non-hardy types of lucerne in North America, the Mount Bar-

ker, Bacchus Marsh, Dwalganup and Tallarook strains of subterranean clover in Australia, and the majority of varieties so far marketed of leguminous forage plants. In self-fertilizing species, such strains may be derived from one single homozygotic plant and are, therefore, very homogeneous and stable. In cross-fertilizing species, in order to avoid the loss of vigour due to inbreeding, strains must be built upon a large number of genetically slightly different plants; the composition of such strains is always unstable. Great care must be taken here to keep the variation within reasonable limits (multiplication within the region of origin, uniform management of seed fields, production of new stock seed after progeny testing, and selection and bulking of the most typical progenies).

In a heterogeneous strain built up of aggressive and non-aggressive, prolific and less prolific, hardy and not so hardy, early and late types, the delicate balance of the different types is easily upset. A season of heavy frost may favour the hardy plants and kill off most of the less hardy, and thus make the strain as a whole more cold-resistant. A seed harvest taken early may result in a considerable change to greater earliness, as only the early types were able to produce ripe seeds. The period of highest frequency of pollinating insects may have a similar influence on the average earliness of the following generation of a strain. This has been clearly shown with red clover in northern Sweden, where the time for emergence of the insects varies considerably, depending upon the conditions of the preceding winter. Again, a close stand may thin out the non-aggressive types and an abundance of plant nutrients may unduly favour the prolific types. It is, therefore, necessary to keep the seed production of such strains under close observation and to carry out comparative trials continuously, to prevent the strain changing to a general type quite different from the original one. A seed certification scheme which provides for continuous supply of new stocks of seed from the plant breeders is an excellent method of guarding against deterioration in strain.

Advanced breeding methods

Breeders have, however, also applied more refined methods to the breeding of leguminous crops. As already mentioned, by means of exposing existing variable strains to artificially induced hardships (drought, frost, epidemics of pathological fungi or of insect and nematode pests), valuable and highly resistant varieties have been produced. In this case, the breeders have used the same methods as nature, but more efficiently. Artificial crosses between strains of different valuable characteristics have been applied to combine these characteristics, thus creating still more valuable

strains. In many cases the barriers of cross-incompatibility in such cases have been overcome by means of artificial chromosome doubling. By chromosome doubling it has been possible to produce new higher-yielding or in other ways preferable strains (e. g. the tetraploid strains of red and alsike clover produced by Scandinavian breeders). Even the induction of artificial mutations by means of X-rays or other agencies has been used to induce greater variability.

In the regularly cross-fertilizing species, inbreeding has been used to make the plant material homogeneous, with subsequent crossing of the most promising and reasonably similar types. Diallel crossing to determine combining ability, followed by judicious selection has, however, so far been the main method in the production of improved strains. Most of the more advanced breeding methods have been applied only recently and to very few leguminous crops. There is reason to believe that the achievements of breeding in the near future will be much greater than they have been so far.

Variety testing

Breeding does not consist only in the production and isolation of new types and strains, for the testing and evaluation of these products is just as important. Usually this takes more of the plant breeders' time than the purely genetical work. This topic will be treated in the next chapter.

With reference to the time needed for breeding or testing introduced types, the breeder seldom achieves a satisfactory result, say, in breeding for resistance to a certain disease, or to drought or excessive moisture, in one step. Usually, he has to build up such a resistance gradually, step by step. As there is no use for a variety which is resistant to one disease and susceptible to all others and to other kinds of hardships, or which gives a low yield of poor quality, the breeder must think always of producing and developing all valuable characters parallel to his special objective. Thus, when a strain sufficiently resistant to a certain disease has been produced, this will most probably be deficient in other characters. Adjustment will then have to be made by crossing with varieties possessing these, and new selection made for a combination of all desirable characters. As the results of each step in the breeding have to be tested and evaluated in various respects and as the end products must pass rigorous and repeated trials, it is obvious that plant breeding is generally very tedious work. In cereals, a period of 10 to 15 years is considered normal for the production of a new variety. In forage plants, and especially in the perennial species, a still longer period is needed, since in this case the trials must have a duration of several

years and in many instances a new generation cannot be produced every year.

The result of any selection or testing of plant material is always dependent upon the environment in which the work is carried out. Those types which are favoured by local growth conditions will be selected and others will be discarded. Breeding and testing should, therefore, be as decentralized as possible in order to utilize the material fully.

An example of how a good service may be established for the testing of varieties and strains of crop plants is the organization of the breeding work of the Swedish Seed Association. The Association has its headquarters and main breeding station at Svalöf in the southernmost province of Sweden, where the favourable climate makes it possible to study all crop plants grown in the country. The main laboratories (physiological, chemical, cytological, pathological, etc.) are also situated there. As Sweden extends from north to south for about 1,000 miles and as some parts of the country consist of fertile plains and others of high mountains, variation in both climatic and soil conditions are considerable. The Association has, therefore, developed a system of eight branch stations distributed throughout Sweden. Independent selection and breeding work is carried out at each branch; for their field tests these breeders use not only their own fields, but also sub-stations in different parts of their respective regions. If, for example, a new cross is made at the main station or at any of the branches, or if a new local strain of herbage plant is to be tested, seeds are sent to all stations in which the material would be grown. Testing and selection then take place independently and often lead to very divergent results as compared with the original cross-progeny or strain.

In areas where improvement of cross-fertilized species by scientific methods has only recently been established it is possible to secure quite appreciable improvements on the local varieties fairly quickly by an intelligent system of mass selection. Also, because of the major improvements which can occasionally be obtained in this way, and because of the complexity of determining relative yields of strains of improved forage plants in ley mixtures, such mass-selected material could, with immediate economic advantage, be released after a limited series of trials, especially where the strains have certain obviously desirable agricultural qualities.

Co-operation beween plant breeders

Co-operation with other breeders is of the utmost importance in securing desirable material and in exchanging experiences of many different kinds. Specific journals, national and international conferences and organized team work have been of great help in this

connection. Recently F.A.O. has initiated comprehensive work in publishing *World Catalogue of Genetic Stocks* of important crop plants, with detailed descriptions of the characteristics of the listed strains and varieties. A start has been made with rice and wheat and supplements to these are issued periodically. F. A. O. also participates in organizing the Working Party on Rice Breeding and uniform trials with hybrid maize strains in Europe and the Near East.

Another good example of specialized co-operation between plant breeders is the Alfalfa Conference in the United States. This is an informal organization of federal, state and other workers directly concerned with experimental or research work on lucerne breeding and improvement, including plant pathologists and entomologists working on this plant. It acts mainly as a working group and holds regular meetings which may also be attended as non-members by other agronomists concerned with lucerne. The active group of plant breeders numbers about 40 to 50, while about 100 usually attend the annual meetings.

The early maize breeding programmes started in the Corn Belt of the United States were rather small and isolated. Because of this no outstanding hybrids were developed. These programmes were expanded in the early 1920's and co-ordinated into a national programme with free interchange of breeding material among the different maize breeders. This facilitated the development of hybrids involving the best inbred lines from several breeders; it was not until this was done that commercial hybrid maize became a reality.

Hand-in-hand with the plant breeding must always go the establishment of agencies for controlled reproduction and distribution of the seed. As long as such facilities are lacking, the benefit of the breeding work can never be fully utilized. The same applies to the introduction of new crop species or varieties from foreign sources – a procedure which plays an important role in the development of agriculture in all parts of the world.

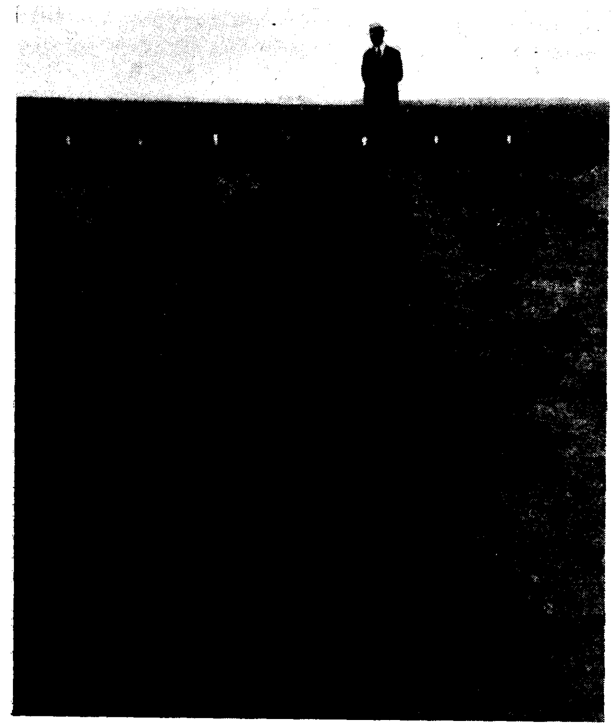


PLATE 27. Differences in resistance to clover stem rot (*Sclerotinia trifoliorum*) in first-year varietal trials of red clover, Svalöf, Sweden. Merkur red clover in centre surrounded by non-resistant local strains.

(Photo by courtesy of the Sveriges Utsädesföreningen)

PLATE 28. Individual plant of red clover infected with northern anthracnose. (*Kaubatiella caulivora*)

(Photo by courtesy of the Division of Forage Crops and Diseases, U.S.D.A.)

PLATE 29. A strain of lucerne susceptible to wilt, growing between resistant strains, Madison, Wisconsin.

(Photos by courtesy of the Division of Forage Crops and Diseases, U. S. D. A.)

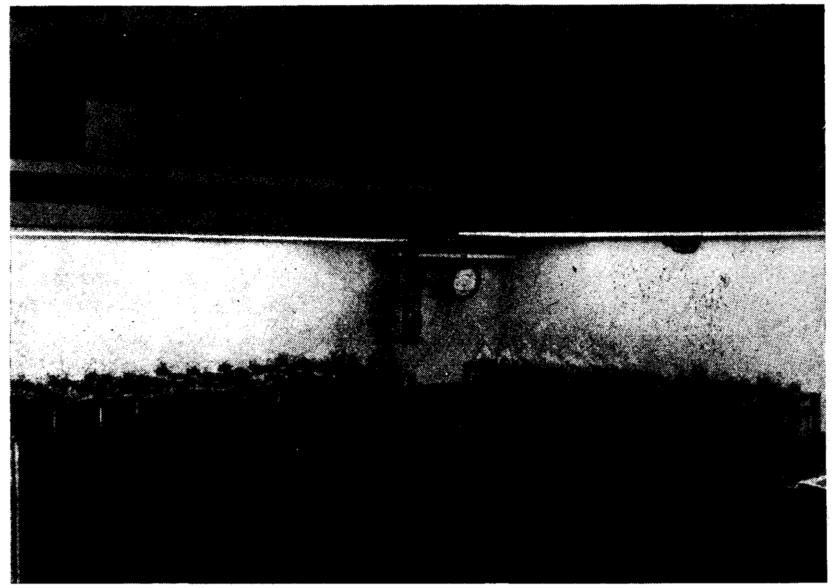
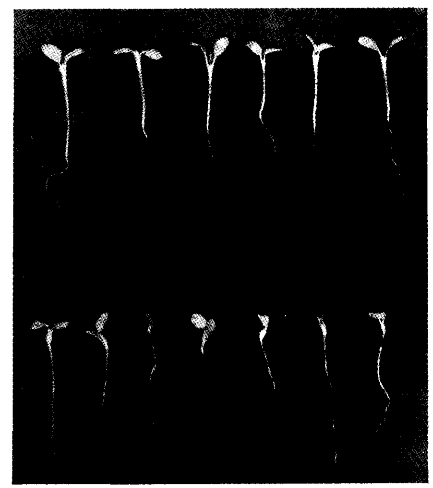


PLATE 30. To test resistance of red clover to nematodes, seedlings are dipped in a suspension of eelworms for some time. The infected seedlings are then grown for a few weeks in filter-paper rolls in a thermostat with artificial light. To promote attacks by the nematodes, the seedlings are covered with glass jars to keep the moisture round the plants.

PLATE 31. Red clover seedlings which had been infected with nematodes two weeks before the photograph was taken. Upper row: healthy; lower row: infected seedlings deformed by the nematodes.



(Photos by courtesy of Sveriges Utsädesföreningen, Uppsala)

PLATE 32. Magnified leaf stalk of susceptible red clover plant showing numerous nematodes and eggs.

PLATE 33. Red clover varietal trial, second-year ley, at Svalöf, Sweden, showing variation in resistance to nematodes. Left to right: Diploid Wambasa, tetraploid Merkur, tetraploid Ultuna. (Photos by courtesy of Sveriges Utsädesföreningen)

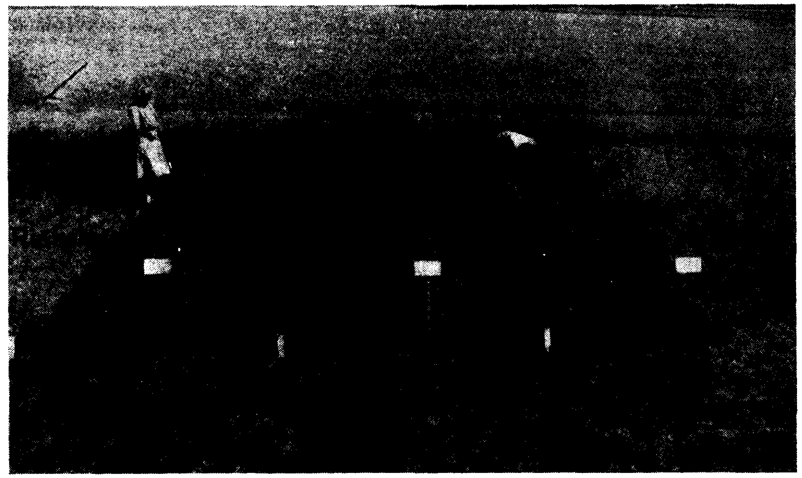
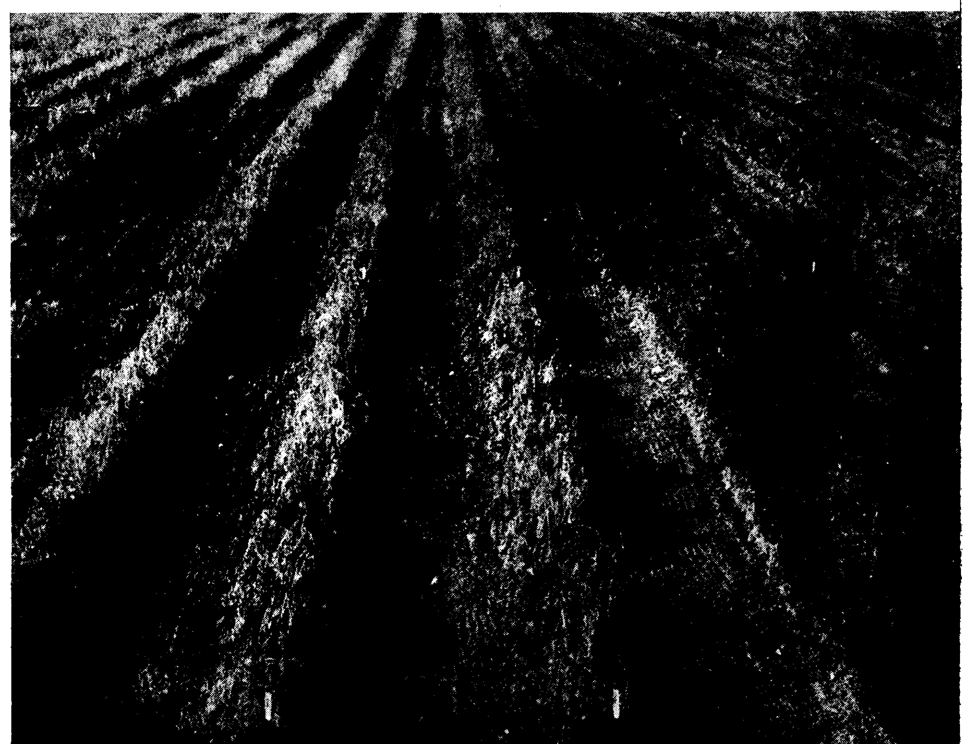


PLATE 34. Differences in winter hardiness in early red clover strains, first-year. Svalöf, Sweden. (Photo by courtesy of Sveriges Utsädesföreningen)

PLATE 35. Rows of lucerne varieties in plots at Arlington, Virginia, showing all have been winter-killed except the three lines in foreground of row beginning from lower right corner. (Photo by courtesy of the Division of Forage Crops and Diseases, U. S. D. A.)



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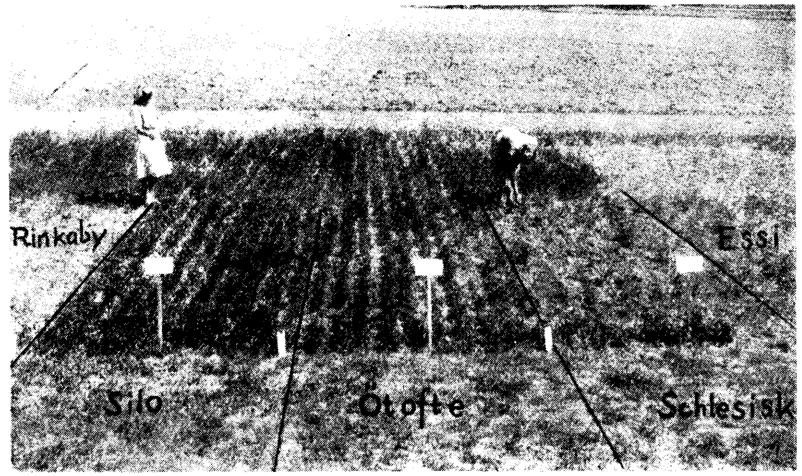

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Chapter Twelve

INVESTIGATION AND TESTING OF IMPROVED STRAINS

Need for repeated trials

Work on the breeding, introduction and management of crops should always start with field trials preferably carried out in several places simultaneously in order to facilitate local practical orientations. There may be some peculiarities in the local climatic or soil conditions, or certain diseases and pests may prevail which could damage the crop if suitable steps are not taken to counteract them. For this reason the introduction of crop innovations directly into large-scale cultivation involving great economic risk cannot be recommended; local conditions must first be investigated thoroughly and measures for avoiding crop failure developed. Even if such precautions are taken, agriculturists always have to be prepared for emergencies due to variable weather conditions, and new diseases and pests which are always liable to appear. The longer the period of the preliminary trials, the smaller the risk of such difficulties.

If there is reason to believe that a leguminous species or strain could be grown with advantage in a region where it has not so far been tested it is not enough to introduce seed of only one strain and from a single source. Care should be taken to test as many different strains as possible simultaneously to obtain an indication of the amplitude of variation within the species and to be able to pick out the most suitable strains. Plant introduction should not be a haphazard importation of any seed that happens to be available. It should be carried out systematically, using all available information relevant for the selection of the material, which should then be tested under different environmental conditions. There are cases where a certain type of plant has at the first test been considered useless for a region, but where later introductions have led to a revised opinion and the new crop plant has become of great importance in that same region. The introduction of cultivated red clover and lucerne to northern Europe is an outstanding example. Non-hardy varieties from the Mediterranean area were first imported. As they could not stand the severe winters, most people considered these species to be quite useless for the countries in question. When, however, more hardy types were found, these two legumes soon became the most important for hay production.

When starting field experiments, it is first necessary to ascertain that the seeds or other planting material are true to type. If a certain type of plant has been successfully cultivated in one growing area and is to be tested in another with similar climatic and soil conditions, it is essential that that actual type is obtained and no other. Certified seed should preferably be demanded, but, if this is not available, some other kind of guarantee of the authenticity of strain should be requested so as not to endanger the whole experiment.

Further, if legumes of the same species have not recently been successfully grown on the experimental plots, inoculation with appropriate rhizobial bacteria should be effected. Preferably a bacterial strain should be used which has already been tested with the crop in question and found to be efficient. In some cases strains from other related species can be used (*see* p. 179). During the vegetative period the roots of the growing plants must be investigated for the occurrence of root nodules. If none develop, the experiment must usually be repeated with seeds inoculated with another strain of bacteria.

In order to be able to generalize about the results of experiments, these should not be carried out in one place only or over a one-year period. They should be repeated in several localities under slightly different conditions and should also be continued over a period of a few years. In this way, the influence of variations in such external factors as temperature, moisture, altitude, soil, etc., will be noted. The results of the experiments will be reliable only if exact measurements of growth and yield of the plots are taken. The development of the crops should also be followed during the whole vegetative period, and observations made on all such external factors as diseases, insect pests and mechanical damage. Chemical analyses of the harvested products should be carried out as far as possible so that the real value of the crops may be estimated.

Field plot technique

An exact indication of the relative value of different treatments in field experiments will, however, be obtained only if the plots are replicated and the experiments designed in such a way that the most important questions may be answered and the inter-relationship of varying factors studied.[1] For this reason also, check plots representing common crops or methods of treatment must be included

[1] For textbooks on these topics *see* *The Design of Experiments*, by R. A. Fisher (Oliver and Boyd, Edinburgh, 4th ed.), 1947, and *Experimental Designs*, by W. G. Cochran and G. M. Cox (John Wiley and Sons, Inc., New York) 1950.

in the experiments. It is obvious that the treatment of the plots should, as far as possible, be the same as the crop would have received in practical farming. Thus, a pasture species should be pastured or treated in a way that closely resembles pasturing. A hay or silage species should be cut at the same stages of development as on a farm. Legumes usually grown in mixtures with grasses should in the experiments be grown in such mixtures, and leguminous plants intended for growing between rows of maize or cane as a mixed crop should be grown in that manner. The influence of a soil improving crop should be measured by the behaviour and yields of succeeding crops.

The evaluation of strains of herbage plants, and especially of pasture strains, is more complicated and liable to more misinterpretations than, for example, the evaluation of cereal varieties. Not only is the forage yield of herbage plants more influenced by external factors but the determination of the yield itself is somewhat difficult. Further, the content of various nutrients and indigestible material changes considerably during the development of the plant, and it is not always possible to find the best time for sampling and harvesting.

It has already been mentioned that in experimental plots with pasture plants, the conditions of actual pastures should be imitated as closely as possible. The biting and tearing off of the herbage by the grazing animals (usually more or less selective) and the trampling and leaving of droppings considerably influence the development of the plant associations and may, in certain cases, completely reverse the results of the experiments. If this principle is fully adopted, as is the case in the final stages of testing at the Welsh Plant Breeding Station, Aberystwyth, and the Grassland Research Station, Stratford-on-Avon, England, we have to rely on grazing animals for the harvesting of the pasture plots. Even if such comparatively small animals as sheep are used for this purpose, the plots must be quite large and the method involves much replication and fencing. The yields of the individual strains or treatments have to be calculated from the production of meat, wool and lambs in the case of sheep and from the production of meat, milk, butterfat and calves in the case of dairy cows. It is obvious that this calculation of yields (in starch equivalents or other comparable units) is rather laborious and subject to many sources of experimental error. There is no doubt, however, that this is the most correct way of carrying out grazing experiments and that it should be used wherever possible.

In many countries, methods of procedure have been designed to simplify experiments in pastures without materially changing the final results. The simplest are those in which the so-called pasture plots are mowed with a lawn-mower and treated with a roller as frequently as they would have been grazed. No doubt

preliminary results can be gathered in this way and a rough estimate of the value of the various treatments can be gained. It should, however, be kept in mind that serious mistakes may arise from such experiments, for example, when strains react differently to the treatment of the grazing animals. Other methods constitute a compromise; two complete trials may be established instead of one, and these may be alternately pastured and mowed, so that at each harvesting date one of the trials will give yield figures and samples for analyses and the other will be grazed. Even if such a procedure is not ideal, it considerably reduces the work and calculations necessary and simulates the conditions of a practical pasture to such an extent that it is quite suitable for experiments running for only a few years. Common methods for collecting data having a bearing on the value of a certain plant under pasture conditions are by sampling rotationally grazed plots before and after grazing, or, in the case of open continuous grazing, by protecting small areas from the grazing animal for periods of 3 to 4 weeks, taking samples from these areas and changing the areas so protected after each sampling.

Only when the results of a carefully conducted series of field trials have shown the desirability of the introduction of some new leguminous crop or method of cultivation, is it advisable generally to recommend that such an action be taken. One must always avoid hasty recommendations which may later have to be reversed. Great damage can be caused in this way not only to the individual grower, but also to the public's confidence in the advising authority.

When strains are to be tested for their practical value, they must pass through several fairly complicated trials before reliable judgement can be given. The first stage is usually simple, and consists of growing single plants, or when possible clones of plants of the respective strains alongside some standard variety and comparing their yield, development, growth habits, resistance to disease and insect attacks, reaction to soil and climatic fators, etc. If the standard variety is repeated satisfactorily, a complicated arrangement of the strains to be tested is not needed. In such a test, most of the strains may be sifted out with some degree of reliability, and the material reduced to one quarter or one fifth the original number. Care must be taken, however, not to place too much reliance on such preliminary tests. They should if possible be repeated and new selections made from each test. It must also be borne in mind that plants which in practical farming are grown in closed stands react very differently when spaced out and cultivated as single plants. Many characters, such as growth habit, leafiness, flowering and seed setting are influenced by the density of the stand and must also be studied in closed stands. Aggressive and less aggressive plants react in quite different ways to the density of the stand.

Aberystwyth Scheme

As an example of how to proceed with a complete test of hay or pasture plants the following scheme for evaluation of herbage plants, adopted at the Welsh Plant Breeding Station, Aberystwyth, has been outlined by Professor E. T. Jones. The scheme consists of two main parts, namely, single plant studies and sward production studies.

Single Plant Studies. These are conducted by the plant breeders, and are directed towards studying the growth form, variation of types within the strain, and the general behaviour of the individual plants forming that strain.

Sward Production Studies. Although the true assessment of pastures and herbage plants can be obtained only through animal production trials, it is impracticable to conduct every trial for each herbage plant on such an extensive scale. As a result, a scheme was evolved about 10 years ago to conduct such trials in stages, each stage being concerned with supplying certain specific information about the strains to be tested under normal farming conditions.

Stage I Trials: Establishment and Preliminary Test

The first step with a new herbage plant is to investigate its ability to establish, and later maintain, itself under the range of conditions normally prevailing. This entails a study of time, depth and rate of sowing, as well as the suitability of various nurse crops for satisfactory establishment. It is also essential to study the ability of the new strain to cohabit with other plants normally included in a seeds mixture when forming a sward, and this under different systems of sward management and manuring as well as under different climatic conditions.

These trials consist of a large number of small plots varying in size from 10 to 25 square yards, thus enabling the investigator to have a sufficient number of replicates under each condition without utilizing an undue area of land. In addition to exact data on establishment and persistency, general behaviour and production are also noted under the various conditions. The plots are grazed on a rotational basis, either all plots grazed as one unit, or preferably each plot is grazed individually, using movable folds to control the animals.

Seasonal production is obtained by eye estimations before each grazing, and exact herbage yields are taken when the herbage

is intended for conservation as hay, silage or dried grass. The yields, where available, as well as constant note-taking in the form of eye estimations throughout the season, enable the investigator to separate the strains useful for any particular purpose from the inferior strains.

Thus, while this method rarely produces data and figures suitable for statistical analysis, it does indicate the place and value of a strain under actual practical conditions with the minimum amount of labour, both technical and manual. It certainly indicates which of the strains merit more critical trials.

Stage II Trials: Determination of the Exact Herbage Production of Various Strains

Only those strains which have shown promise in the Stage I trials under a certain condition are included for that condition in the Stage II trials. The trials resemble those of Stage I in that they are conducted under one or more actual farm conditions of management. They differ in that each plot is grazed on its own at all stages, and the number of animal grazing days recorded. In addition, small areas or quadrats of herbage within each plot are cut before each grazing, but no area is sampled twice within the one season, and generally not within two seasons. The samples are weighed to determine the total yield of herbage at each grazing, botanically analysed to find the contribution of each species, also analysed chemically.

When and where the investigations are concerned entirely with herbage production for conservation, these trials are simpler, as the whole plot is harvested for determining the yield and composition of the herbage, and fencing can be omitted. In some cases, however, a strain may fill a dual role in providing grazing for part of the season and herbage for conservation at other times, e. g. hay plus aftermath grazing, or early and late grazing plus one or more cuts for silage or artificial drying during mid-season. As long as the plots are individually fenced, it is relatively simple to combine grazing and conservation on the same plot at different times of the year.

Thus, in the Stage II trials, the emphasis is laid on obtaining the yield and composition of the herbage produced on plots composed of different herbage plants without superimposing an artificial system of management.

The size of plot used at the Welsh Plant Breeding Station for conducting Stage II trials varies from 50 to 100 square yards when studying the herbage produced entirely for conservation, and from 150 to 400 square yards when studying herbage production under a system involving grazing, the lower limit being useful for sheep grazing, the upper for cattle grazing.

Stage III Trials: Testing the Relative Value of Herbage Plants in Animal Production

While Stage II trials give most of the evidence needed for the evaluation of herbage plants, the need occasionally arises for checking the results obtained with the results of animal production trials. The actual feeding value of any herbage may fall short of the potential feeding value calculated from the yield of nutrients obtained in Stage II trials. This may be due to a poor balance of nutrients, or even to a deficiency or an over-abundance of some particular nutrient in the herbage, all of which may seriously affect the health and well-being of the grazing animal. Therefore, when the total yield of nutrients of swards containing the new herbage plant approaches or surpasses that of the prevailing popular mixture, it is necessary whenever possible, to compare their actual animal production and monetary returns.

Only a few of the most promising strains in Stage II can be introduced in these trials. Although the number of plots is small, the size of plot must be sufficient to carry a number of animals for relatively long periods. The area of land necessary for each strain varies from about 2 to 20 acres or more, according to the class of animal used for grazing and the fertility of the land.

Simplified trials

It is obvious that a complete scheme for the testing of improved plant material, as outlined above, is always desirable but is very often impossible to carry out fully because of lack of sufficiently trained personnel and facilities of different kinds. In such cases simplified methods and certain approximations have to be relied upon. This must naturally be done intelligently, recognizing that mistakes may eventually occur and that, therefore, the results of such simplified tests must always be critically examined. More especially in the early stages of breeding and plant introduction when great differences in material can be expected, success can, however, be gained by rapid and simple methods. An outline for such a procedure might be as follows:

A start might be made from single plants or single rows of plant progenies or eventually from small broadcast or drilled plots of strains collected from different sources. These tests should be carried out at one or only a very few localities. Preferably they should be repeated a few times, but simultaneously the best strains are picked out for replicated trials under more practical growth conditions and on a larger scale (hay or pasture plots etc., eventually in mixture with suitable grasses, as outlined above). As the number of strains thus successively diminishes, the size of the plots can be

increased and in a few years a fairly good idea of the remaining material may be obtained. In such tests, weighings of hay or silage should be made, but the evaluation of pasture strains may to a great extent be based upon mere observations of the behaviour of the strains under grazing (spreading, covering of the soil, resistance to trampling, persistence and periods of maximum production, etc.). Further experiences might be gained by distributing seed of the best strains to a few selected farmers and observing their behaviour under practical conditions for a few years.

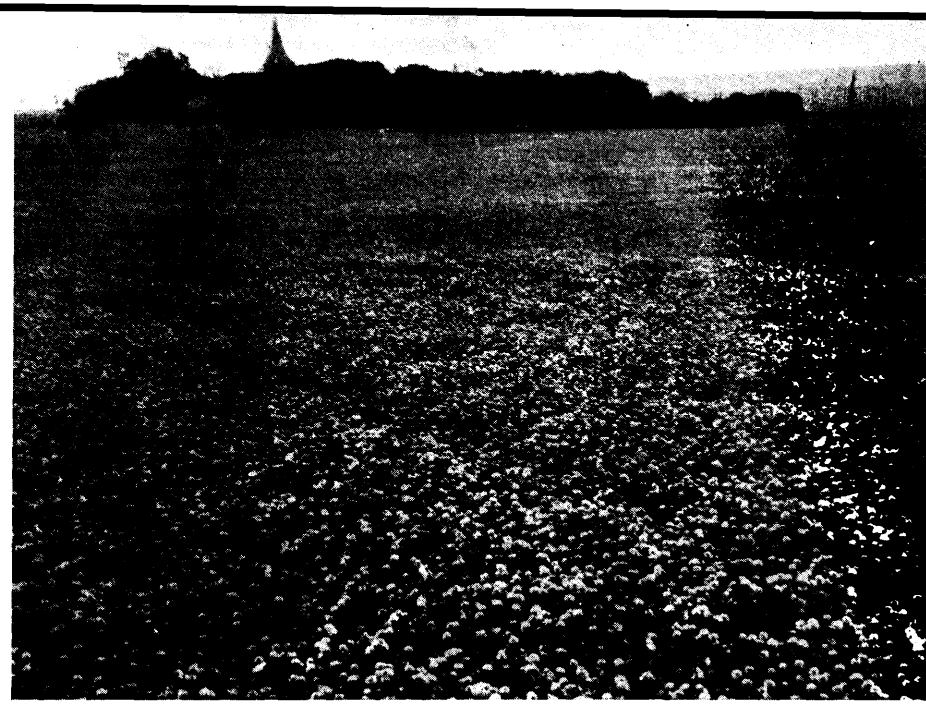


PLATE 36. Seed field of Svea alsike clover, Svalöf, Sweden.
(Photo by courtesy of Sveriges Utsädesföreningen)

PLATE 37. Four beehives per acre used for pollination in a Ladino white clover seed production field in California, U. S. A.
(Photo by courtesy of the Division of Forage Crops and Diseases, U. S. D. A.)

PLATE 38. Harvesting white clover seed in Idaho, using windrower attachment to mower.
(Photos by courtesy of the Division of Forage Crops and Diseases, U. S. D. A.)

PLATE 39. Ladino white clover being harvested from windrows in California, U. S. A.

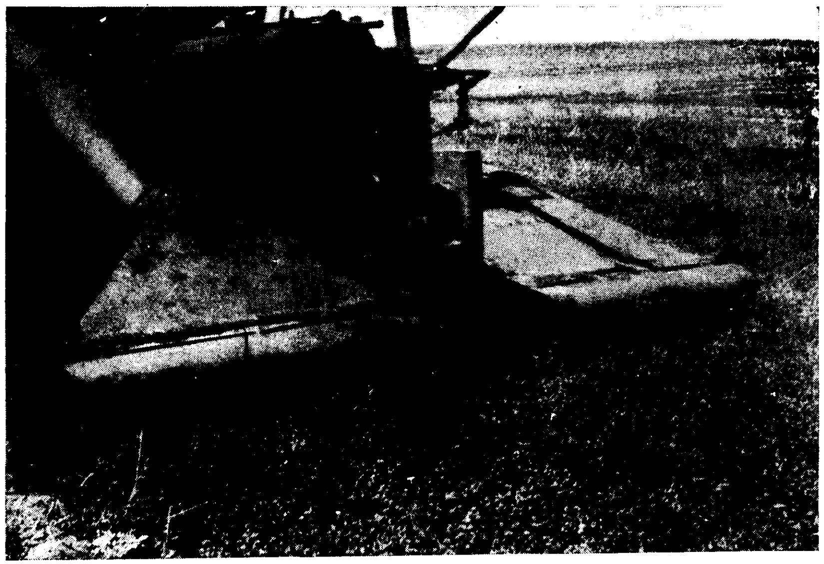
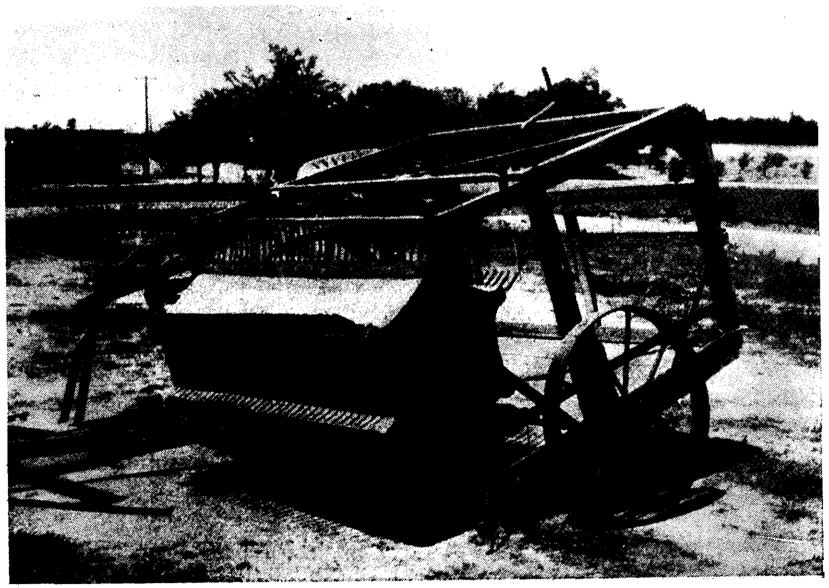


PLATE 40. Home made suction machine for harvesting Ladino white clover in California.

(Photos by courtesy of the Division of Forage Crops and Diseases, U. S. D. A.)

PLATE 41. Home made stripper used for harvesting crimson clover seed in the U. S. A.



Chapter Thirteen

PRODUCTION OF SEED

The production of seed from pasture, fodder and green manure legumes (omitting the grain legumes from this part of the discussion) is, in many cases, a specialised form of crop husbandry which has to be carried out at a high standard to be successful and economical. It will be possible to refer here to only a few of the factors which have to be considered.

Legume seed production is in some countries haphazard and somewhat primitive, in others, specialized and technically efficient. The former type is merely an adjunct to fodder production, a decision being made to take a seed crop following a period of good conditions for seed setting. The latter type entails the growing of strains primarily or solely for seed. The seed grower is then able to adopt the technique most suitable for the production of maximum yield and quality. Although in England excellent seed crops are grown on many livestock farms, there is more scope for professional growers of herbage seed on farms organized primarily for crop husbandry. Where the farmer wishes to grow and obtain economic return from a ley crop without necessarily keeping livestock the seed production ley is a useful alternative and contributes considerably to the maintenance of soil fertility. Such conditions arise in England, Denmark and southern Sweden, for example.

In the clovers, seed is in many cases taken from the first cut of the year, but in order to adjust the flowering time to the time when pollinating insects are most numerous, it is often desirable first to take an early cut for silage, artificial drying, green fodder or hay, and to harvest seed from the second. In the early or double-cut strains of red clover, seed should always be harvested from the second cut of the year. The regrowth of any later types which may eventually appear will produce little or no flowers and seed, thus keeping the earliness of the strain constant. In lucerne, the seed crop is taken from one of the two or more cuts made in a season, a decision as to the exact cut to be taken being dependent on local seasonal conditions and farming practice.

The strains of cross-fertilized legumes, such as lucerne and the clovers, are very variable and easily influenced by environment. If the seed grower wishes to keep his strain well adapted to the growing conditions of the region and to preserve its hardiness and resistance to disease, he should allow natural selection to operate

to the full before taking a seed crop from a stand. This means that seed of the perennial species should not be harvested in the first year of growth, and preferably only from rather old stands which have become considerably thinned out. Since, however, such a method will considerably reduce the yield per unit area and will generally increase the amounts of weed seeds in the harvested lots, it is not applicable in seed production on a commercial scale. For the production of stock seed, on the other hand, such a procedure can be recommended and constitutes a simple method of continued re-selection of valuable and well-adapted strains.

It should be noted that there is a marked distinction between the production of seed from bred strains of grasses and of clovers. The breeding of grasses for leafiness necessarily means the selection of rather vegetative types from which it may be somewhat difficult to obtain good and economic seed yields without special selection of seed production areas, or the development of special techniques. This does not apply so much to bred strains of legumes. Extra productivity of green mass does not imply a lower production of seed to the same extent. However, very dense, luxuriant stands of red clover will in a humid climate tend to lodge, particularly when rainfall is excessive, during the period of most rapid growth, and the seed yield may be reduced considerably by the rotting of the lower leaves and seed heads.

A number of factors govern location of site for seed production. In Great Britain, clover seed crops are almost wholly grown in areas enjoying abundant sunshine and adequate showers, with an average annual rainfall between 20 and 30 inches. In the United States, lucerne seed production is most dependable where the climate is relatively dry, especially during the flowering and ripening season; such conditions are found in the arid and semi-arid districts of the West, where the necessary moisture is supplied by irrigation.

Most of the red clover seed in the United States is produced in the Corn Belt states, but there appears to be little possibility of extension in this area to meet the increasing demand. Authorities believe that the production of red clover seed may be considerably increased in the inter-mountain states, where the farmers look to red clover as a one year ley in rotation with potatoes, beans and sugar beet, also as a marketable crop adapted to haulage over long distances when harvested for seed.

Although clover seed yields are better than grass seed yields on light lands of lower fertility (unless they are liable to dry out rapidly), it is said that " the lower the average spring and summer rainfall, the more fertile the land should be for legume seed production".

When the quantity or quality of seed produced is very low in a region where a certain strain originated or where it is well adapted for fodder production, it becomes necessary to contemplate seed

production in another region with better conditions. Certain problems then arise with the cross-fertilizing species, the clovers, lucerne and others. Strains which are always more or less heterogeneous and heterozygous are easily and quickly influenced by natural selection if grown in areas where the climate is even slightly different from that in the region of origin or common use. Just as natural selection is very valuable in adapting plant material when a new species or strain is introduced to a country or region, so can it be just as great a danger in a new region, since within a few generations the type of the strain may be considerably changed and its valuable adaptation to growth conditions in the region of fodder production may be lost. In such cases, foundation seed must be grown continuously in the region of origin or of fodder production – even at a rather high cost – and be sent to the seed-growing areas for the production of only one generation of seed. When the seed fields are ploughed up or the crop is changed, new foundation seed should be obtained from the same source.

If strains of legumes are moved for seed production from a higher to a lower latitude or *vice versa*, the influence of light periodicity becomes important, at least in certain legumes. Experience in Scandinavia shows that when red clover strains from the northernmost parts are moved some 5 degrees of latitude south, they do not set seed freely and cannot be propagated successfully. Lucerne does not seem to be affected to the same degree. It is true that in northern Europe the seed production of lucerne is generally very poor, more because of the moist summer climate than the long days of northern latitudes. This is clearly shown by the good seed yield occasionally obtained in these countries after comparatively dry and warm growing seasons. In these instances, the seed yield of strains from very different latitudes is almost equal.

Whereas tropical kudzu (*Pueraria phaseoloides*) is a fairly good seed producer in most tropical countries, this is not so in sub-tropical countries, for reasons which are not yet clear. Some tropical countries also complain of poor seed setting, e. g. Malaya. This might be due as much to variations in air humidity or other factors as to difference in latitude or light periodicity.

Since the clovers and lucerne are both cross-pollinated by bees, the degree and nature of insect activity and the distance of isolation between seed plots are questions of great importance in seed production.

White and alsike clovers can be pollinated by all kinds of bees, but bumble bees (*Bombus*) work much faster in red clover flowers than honey bees; as distinct from honey bees, they are able without moving from the place where they first landed on the flower head to insert their tongues in a great many florets. Their tongues are long and can easily reach to the bottom of the corolla tube to the nectary. Long-tongued honey bees work somewhat better in red clover flowers

than the shorter-tongued types. Both types of honey bees are, however, of great importance in pollination, especially in regions where bumble bees are rare. The honey bees' chief interest is the collection of pollen, and the presence or absence of competing plants will decide whether or not they are very effective on the red clover.

In northern Scandinavia, where bumble bees frequently emerge too late after a long, cold winter to coincide with the main flowering time of red clover, seed crops may be complete failures in such years in localities where honey bees are rare. In the last few years experiments on domestication and breeding of bumble bees were quite successful in Sweden. This might mean a solution of the problem of clover seed production in the northernmost parts of the country.

In order to adjust the red clover flower to the honey bee, breeding has been started in many places to produce strains of clover with shorter corollas. Conversely, attempts have been made to breed honey bees with longer tongues. Efficient growers of clover and lucerne seed in regions where bumble bees are not very frequent either keep bees themselves or contract with beekeepers to place hives in their seed fields at the time of flowering, thus achieving two objectives at the same time.

A number of apparently minor factors become of great importance in the use of bees for legume pollination. Honey bees occupying hives placed in the middle of a red clover seed field are likely to forsake the clover bloom and concentrate on a nearby bright yellow highly scented field of rape or mustard; they will generally prefer alsike or white clover or species of *Melilotus* to red clover.

In parts of India berseem (*Trifolium alexandrinum*) does not set seed because of lack of pollinating insects, and an experiment conducted in the Botany Division of the Indian Agricultural Research Institute, New Delhi, showed that honey bees were the active agents.

In northern Canadian prairies, the solitary bees which are most useful in cross-pollinating and tripping lucerne live in old fallen trees. They live almost entirely in wooded areas. Honey bees are effective in tripping lucerne only under certain conditions. Reports of failure greatly exceed reports of success in this respect. In the lucerne seed producing areas in California, however, farmers arrange to have an adequate number of hives in their seed fields.

Where improved strains of clovers are grown for seed, steps have to be taken to ensure that the type is not contaminated by pollen from wild plants or other strains in the vicinity. In Great Britain, experienced growers are generally able to arrange for their fields to be far enough from offending pollen. The same strains may be grown for grazing or fodder throughout the farm as are cultivated for seed, thus tending to flood the district with only one type of pollen. The efficiency of isolation by distance depends on several factors, including the number of inflorescences, and the relative

sizes of the seed fields as compared with those sown to other varieties. Work at Aberystwyth indicates that the distances previously recommended for isolation might be considerably reduced provided that the seed fields bloom abundantly, and especially if intervening strips of the same strain are allowed to release pollen for the seed crop before they are cut for fodder.

Table XXXII gives minimum distances between fields to be certified and other fields of the same species, prescribed by the International Crop Improvement Association and applied in the United States and Canada. It is generally understood that these may be varied to some extent, according to density of stand, size of seed plot, direction of wind, and other factors.

Table XXXII. Distance Isolation (in feet) in the United States and Canada

Field Acreage	Foundation Seed		Registered Seed		Certified Seed	
	Under 5	Over 5	Under 5	Over 5	Under 5	Over 5
Lucerne	1 320	1 320	330	660	165	330
Birdsfoot trefoil	1 320	1 320	330	660	165	330
Red clover	1 320	1 320	330	660	165	330
Sweet clover	5 280	5 280	660	990	165	330
White clover	5 280	5 280	495	990	330	495
Crimson Clover	1 650	1 650	495	999	330	495

The minimum distance isolation for certified seed crops in Great Britain is 600 feet, but this may be reduced to 150 feet for fields of over 5 acres with full stands.

We can but touch upon some of the other factors which should be considered. A healthy and vigorous stand depends on an initial clean, well-prepared seed-bed, adequate lime status, and potash and phosphate as required subsequently. Diseases and insect pests require attention, and weeds are important both in competing with the growing crop, and in complicating the seed cleaning processes. Seeds have to be closen with full knowledge as to their authenticity, viability, capacity to produce normal or abnormal seedlings, and "hard" seed content. Local tradition and experimentation will decide whether it is best to sow the legume in mixture with grasses, whether a nurse crop should or should not be used, and whether the stand is to be used only for seed, or for grazing or hay and silage cuts as well. The seed crop in northern latitudes is greatly dependent on the effects of over-wintering, and these in turn depend on the treatment of the crop in the previous late summer and autumn.

The harvesting of legume seed crops requires special care in various respects. Seeds do not ripen uniformly in many species, and a decision has to be made as to the stage of development when the highest yield of mature seed can be obtained. Loss of seed through

shattering has to be reduced to a minimum by the use of special trays, etc. When combines are used, excessive speed of the cylinders has to be avoided to prevent damage to the seeds. Great care has to be taken to clean out all machinery, sacks, etc., especially where seeds of improved strains are being harvested and cleaned. Seed cleaning has, of course, to permit the removal of all grass and weed seeds with a minimum of damage to the legume seed. In more humid environments, artificial drying of seed may be necessary before storage.

C. P. Wilsie, formerly agronomist at the Hawaii Agricultural Experimental Station, stated, in 1935, that " while the use of legumes for green manuring and forage has received a great deal of attention both in the temperate zones and in the tropics, little information is available on the seed production possibilities of many of the species that show promise in tropical and sub-tropical agriculture ". After quoting earlier work on the production of seed of *Stizolobium deeringianum*, *Phaseolus aconitifolius*, *Crotalaria spectabilis*, *C. juncea*, *Cajanus indicus* and other species, he gives the results of his own observations on months to maturity, spacing of plants within the row, and yield per acre, for a number of legumes under Hawaiian conditions.

Table XXXIII shows two years' seed yields of certain tropical legumes when plants are in rows 5 feet apart.

Table XXXIII. Seed Yields of Tropical Legumes

Species	Months to Maturity	Yield per Acre. in lb. Space between Plants		
		6 in.	12 in.	24 in.
Crotalaria usaramoensis	7	915	1 154	816
C. spectabilis	5	1 050	782	560
C. juncea	5–6	938	1 074	596
C. anagyroides	9	1 102	784	510
C. grantiana	8	2 830	1 950	1 586
Phaseolus mungo	4	1 136	991	632
Ph. lathyroides	4	493	264	123
Cicer arietinum	4	403	381	254
Ph. aconitifolius	3–4	934	730	393
Cassia occidentalis	8	5 794	2 657	2 853
Canavalia ensiformis	7	3 528	3 071	2 146
Stizolobium deeringianum	7	2 439	2 004	1 797
Stizolobium deeringianum	7–8	3 136	2 526	1 971
Melilotus alba annua	6–7	1 699	1 612	1 345
Medicago sativa	5	722	698	650
M. sativa	5	864	738	556
Tephrosia candida	13	1 090	1 046	458
T. noctiflora	8	3 245	3 006	1 802
Leucaena glauca	10	5 488	3 006	2 146
Ph. calcaratus	3	328	202	132
Desmodium uncinatum	4–5	518	394	282

Care in the production and harvesting of improved varieties of legumes is of little avail without proper control as to trueness of type, etc. This involves certification of seed crops by approved authorities or organizations where these exist, together with the other steps usually taken in more advanced countries to ensure that the farmer receives properly authenticated seed of known type and performance. The concluding sections of this chapter give as example a summary of the seed certification scheme in New Zealand, and the section from the publication No. 17, December 1950, of the International Crop Improvement Association *Minimum Seed Certification Standards* with reference to alfalfa.

New Zealand certification scheme

Commencing with the certification of seed potatoes and seed wheat in 1928, the New Zealand Department of Agriculture has extended its activities in this direction to include such crops as perennial ryegrass, Italian ryegrass, short-rotation (HI) ryegrass, cocksfoot, timothy, brown-top, *Phalaris tuberosa*, white clover, cow-grass (broad red clover), Montgomery red clover, subterranean clover, oats, barley, sweet blue lupins, onions, chou moellier, rape, kale, turnip, and swede seeds.

The scheme was introduced to provide the buyer of certified seeds with a guarantee that the produce of such seeds would be true to type and free from seed-borne diseases.

In the early stages of the scheme, certification, which has relationship only to the type of the plant and not to the purity or germination of the seed itself, was based on the identification of superior strains of seeds appearing in certain districts as a result of natural selection. At the same time, however, a programme of scientific plant selection was instituted by the Department of Scientific and Industrial Research in an endeavour to improve still further the naturally occurring strains. The results of this selection work now form the basis of seed certification as applied to most of the above-mentioned types.

The task of raising seed of artificially selected strains involves in the first instance the testing of a large number of individual plants of the particular species. Only the plants giving the best performance under trial are resown for further multiplication, possibly half a dozen out of thousands.

These plants are then seeded together to produce small quantities of seed of the selected strain. This seed, in turn, is multiplied until sufficient is available to sow areas on a field scale. At this stage the Department of Agriculture takes over the material available and multiplies the seed under contract with selected farmers.

The resultant seed is distributed by the Department, sales being made through the mercantile firms to those farmers most favourably situated to make the best use of it for further seed-production. From this stage the selected strain is multiplied under the Department's certification scheme through the stages of certified " Pedigree " seed and certified " Mother " seed to certified " Standard " or " Permanent Pasture " seed. These seeds are sold through the usual commercial channels.

While in the lower classes of some varieties of certified seed at the present time there may be included also seed from natural strains, the proportion of the latter is being steadily reduced. The purpose of the various classes is to obtain the greatest bulk of good-quality seed in the " Standard " or " Permanent Pasture " class in the shortest time. Thus, while the higher grades are important to seed producers, farmers sowing for pasture purposes only need not concern themselves with other than certified " Standard " or " Permanent Pasture " seed.

Alfalfa seed certification standards of the International Crop Improvement Association

I. Application and Amplification of General Certification Standard.

1. The General Seed Certification Standards, as adopted by the International Crop Improvement Association, are basic and together with the following specific standards constitute the standards for certification of alfalfa seed.

2. The General Standards are amplified as follows to apply specifically to alfalfa seed:

   (1) Section E. Classes and Sources of Certified Seed

   (*a*) When a variety is grown outside its designated region of adaptation, certification shall be limited to one generation from foundation or registered seed. The seed thus produced shall be the certified class.

   (*b*) When a variety is grown within its designated region of adaptation, certification shall be limited to three generations of increase from breeder seed. The three generations shall be: (*i*) foundation, (*ii*) registered, and (*iii*) certified.

   (*c*) The region of adaptation for seed production of a given variety shall be that recommended by the Plant Breeders of the Alfalfa Improvement Conference and approved by the Bureau of Plant Industry, Soils and Agricultural Engineering, or similar research agency in Canada.

II. Land Requirements

1. Breeder seed for the production of foundation seed shall be planted on land on which no alfalfa was grown or planted during the four years prior to the one in which the present stand was planted. The land must be free from volunteer plants as determined by field inspection during the season in which the seeding is established. As an additional precaution, no manure or other contaminating amendments shall be applied during the establishment and productive period of the stand.

2. Foundation seed for the production of registered seed shall be planted on land on which no alfalfa was grown or planted during the three years prior to the one in which the present stand was planted. The land must be free from volunteer plants as determined by field inspection during the season in which the seeding is established. As an additional precaution, no manure or other contaminating amendments shall be applied during the establishment and productive period of the stand.

3. Registered seed for the production of certified seed shall be planted on land on which no alfalfa was grown or planted during the year prior to the one in which the present stand was planted. The land must be free from volunteer plants as determined by field inspection during the season in which the seeding is established. As an additional precaution, no manure or other contaminating amendments shall be applied during the establishment and productive period of the stand.

III. Field Inspection

A field inspection shall be made each year at the time the seed crop is in bloom.

IV. Field Standards

1. General

   (1) *Unit of Certification.* A portion of a field may be certified if the area to be certified is clearly defined. Portions of a field not meeting requirements for certification must not be allowed to reach the seed stage.

   (2) *Isolation.* A field producing foundation, registered or certified seed must have the minimum isolation distance from fields of any other variety or fields of the same variety that do not meet the varietal purity requirements for certification, as given in the following table:

Class	Fields of Less than Five Acres	Fields of five Acres or More
	Rods	
Foundation	80	80
Registered	40	20
Certified	20	10
Between different seed classes of same variety	10	10

(3) *Volunteer Plants.* Volunteer plants shall be cause for rejection or reclassification of a seed field.

(4) *Seed Fields Outside Region of Adaptation.* Certification of seed fields outside regions of adaptation of a variety shall be limited to stands not exceeding six years of age.

2. Specific Requirements

Factor	Maximum Permitted in Each Class		
	Foundation	Registered	Certified
* Other varieties	0.2 %	0.5 %	1.0 %
Sweet clover	None	10 plants per acre	160 plants per acre

* Other varieties shall be considered to include off-type plants and and plants that can be differentiated from the variety being inspected.

V. Seed Standards

Factor	Standards for Each Class		
	Foundation	Registered	Certified
Pure seed (minimum)	98.0 %	98.0 %	98.0 %
Other crops (maximum)	0.10 %	0.10 %	0.50 %
Sweet clover (maximum)	9 seeds per lb.	90 seeds per lb.	180 seeds per lb.
Inert matter (maximum)	2.0 %	2.0 %	2.0 %
Discolored seed (maximum)	–	–	–
Weed seed (maximum)	0.10 %	0.20 %	0.50 %
Total objectionable weeds (maximum)*	None	None	None
Total germination and hard seed (minimum)	80.0 %	80.0 %	80.0 %

* Objectionable weeds in alfalfa are: bindweed (*Convolvulus arvensis*), Canada thistle (*Cirsium arvense*), dodder (*Cuscuta* spp.), dogbane (*Apocynum cannabinum*),, Johnson grass (*Sorghum halepense*), leafy spurge (*Euphorbia esula*), perennial sow thistle (*Sonchus arvenis*), quackgrass (*Agropyron repens*), Russian knapweed (*Centaurea repens*), and white top (*Lepidium draba*, *L. repens*, *Hymenophysa pubescens*).

Part II

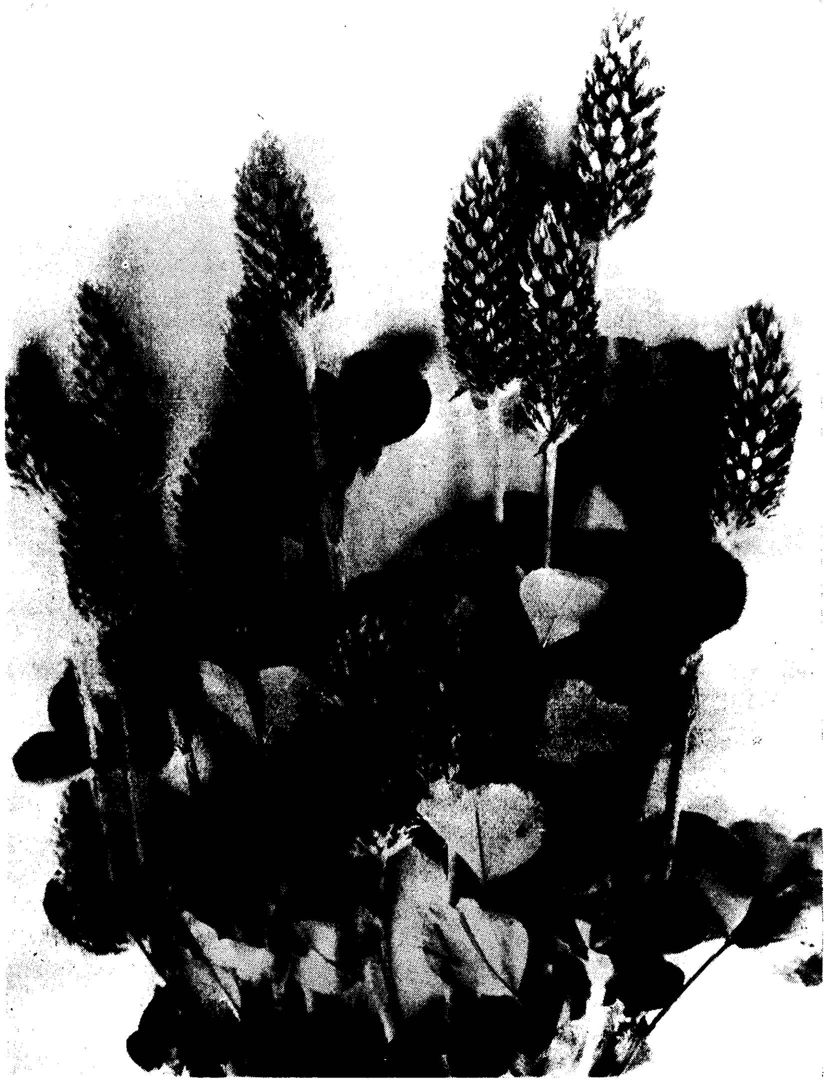


PLATE 42. Crimson clover (*Trifolium incarnatum*)

Photo by courtesy of the Division of
Forage Crops and Diseases, U.S.D.A.

GENERA AND SPECIES *

ACACIA

Some 450 species of *Acacia* are indigenous in the tropical, subtropical and temperate zones. They are especially abundant in Australia, the savannahs of Central America and in Central Africa. Acacias are trees or shrubs and less frequently, herbs. They have a very rapid-growing main root which reaches considerable depths, making them drought resistant; they also have strong horizontal roots in the upper layers of the soil. The leaves are generally bipinnate with many pairs of leaflets, and the flowers appear in clusters and are mostly white. Many Acacias have long sharp thorns and are therefore not readily eaten by livestock.

Species of *Acacia* in the natural vegetation, especially in arid regions, are important as reserve fodder. The leaves and the nutritive pods are browsed or the trees are lopped. They are often cultivated for this purpose, also as shade trees or soil improvers, or for binding sand dunes or controlling soil erosion. *Acacia* spp. are propagated by seeds or cuttings. The seeds usually need scarification, as the percentage of hard seeds is high. In the Sudan, *A. senegal* which produces gum arabic is incorporated as the resting phase in a rotation on sandy soils to improve their nitrogen and humus content (the so-called "gum rotation"). Similar cultivation of *Acacia* between main crops occurs in Sind, Pakistan. Acacia may encroach on improperly grazed pastures and become a noxious weed; it may be eradicated by burning and resting the land from grazing, or by cutting in late summer or autumn 2 to 3 inches from the ground and painting the stumps with a water solution of sodium arsenite or arsenic pentoxide or with paraffin (South Africa).

The toxicity of *Acacia* species depends upon their content of cyanogenetic glucosides. *A. giraffae*, *A. lasiopetala* and *A. litakunensis* are toxic in South Africa. The poisonous effect of *A. georginae* only when eaten with *Stenochilus maculatus* has been mentioned (*see* Chapter VIII). When poisoning is suspected, only small quantities of *Acacia* leaves or pods should be fed, and they should not be moistened with cold water.

As so many *Acacia* species are of value, many only in very limited areas, we can mention only a few briefly:

A. alba (= *A. leucophloea*) is a fodder tree of India, and *A. albida* is used for the same purpose in Uganda, Nyasaland, the

* Poisonous species are indicated with an asterisk.

Sudan, Northern Rhodesia and the Gold Coast. Its pods are often stored and fed dry, which is not possible with many other species. *A. aneura*, widespread over Australia, is a gregarious species forming the well-known mulga scrubs; it is a very important fodder tree in many parts of Australia. *A. arabica* (babul) grows in dry regions but can also endure floods. The pods and leaves are excellent fodder, available when there is no grass. In India, the trees are both lopped and browsed, and the pods are collected for fodder. This species is used there in rotation with grass in order to improve the soil. With *A. nilotica*, it is conspicuous in the tree flora in areas of the Sudan annually flooded by the Nile. This species is an important fodder tree in Queensland, but there it may become a noxious plant. *A. aroma* (= *A. lutea*) is an important fodder for the dry and hot season in dry central Argentina; its pods are palatable and of high forage value, and it grows even on depleted soils.

A. caffra is a fodder tree in the Transvaal and a few sheltered places in the Orange Free State where the frosts are not severe; its small pods are seldom eaten but the foliage is eagerly browsed. *A. cavenia* is used in Argentina for the control of soil erosion; its occurrence wild is considered to indicate poor land unsuitable for arable farming.

A. decurrens and *A. elata* are high altitude trees used in Java for shade; the former is used in Ceylon and the Belgian Congo for green manuring, being pruned two or three times each year. In New South Wales and Queensland *A. excelsa* (ironwood) * has some importance for fodder but is somewhat poisonous. *A. farnesiana* (mimosa bush) is widespread in Queensland, where leaves and pods give excellent feed for sheep. It is very thorny and in some places is considered a pest, in others used for hedges. *A. giraffae* * is a fodder tree of the karroo and broken veld in the Transvaal and parts of Cape Province. Although the pods are cyanophoric they are used for fodder. The tree is propagated by seeds or cuttings; the seeds must be treated with cowdung to promote germination.

The leaves and twigs of *A. implexa* and *A. maidenii*, two similar species, are eaten by stock in Queensland during dry periods; the trees are often lopped. *A. karroo* is a fodder tree of the Cape Province and Transvaal; it is easily propagated by seeds but seedlings are very sensitive to frost and cold winds. *A. koa* is a tree of great adaptability and excellent fodder value occurring in Hawaii and the wet tropics. The pods and seeds of *A. lasiopetala* * and *A. litakunensis* (= *A. spirocarpoides*) * are used for fodder in the South African karroo and broken veld. They are somewhat cyanophoric. The latter species thrives on phosphorus-deficient soils, but is rather sensitive to frost. *A. mollissima* (black wattle) is grown in South Africa mainly for tannin, but it may also serve as an emergency feed. Its soil improving properties are doubtful. If the trash is allowed to decompose instead of being burnt, the

succeeding crops may benefit considerably. In Argentina (Tucuman), the tree or shrub species, *A. moniliformis*, has very nutritive pods which are avidly eaten by livestock.

A. robusta grows on the karroo and broken veld in Cape Province and Orange Free State; sheep browse it readily and its pods may be used as concentrates. *A. senegal* has already been referred to above. *A. seyal* is important as fodder for dry periods in the Sudan and Nigeria; the flowers are especially palatable to sheep and goats, but the pods are less nutritious. *A. sieberiana* is a good shade tree in Uganda, but only if water is abundant. *A. pendula* and *A. sowdenii* (both called myall) provide an important source of fodder in arid regions of Australia. *A. villosa* is a shrub used for green manure in Indonesia, propagated by seeds. *A. victoriae* is an important fodder shrub in semi-desert areas subject to flooding in Western Australia. It forms seed abundantly and regenerates moderately well. During the early stages the plant is very prickly and thus well protected from grazing animals. Pods of *A. woodii* are valued as stock feed during the winter months in Northern Rhodesia.

ADESMIA

This genus is indigenous in South America, from Patagonia in the south and throughout Argentina, Chile, Uruguay and the high Andes of southern Peru, from extremely dry areas to localities with 217 inches of rainfall per year. There are both annual and perennial shrubby and herbaceous species, which have a high protein content and are useful as pasture plants, as a forage resource in regions of long summer droughts and for soil conservation.

A. bicolor is a stoloniferous perennial with great vitality and good power of recovery even after continuous grazing during very dry periods. It is especially abundant in pastures on fertile soils of northern Argentina and Uruguay. Other species are *A. herteri*, *A. latifolia* and *A. muricata*.

AESCHYNOMENE; Joint Vetch

Aeschynomene, or joint vetch, has about 70 species native to warmer regions of Australia, America, Africa and Asia, characterized by flattened pods with several easily separated joints and by odd pinnate leaves. As constituents of the natural vegetation most species have some value as browse or pasture plants. A short-lived perennial, *A. americana*, is indigenous to tropical America and is used in Indonesia for green manure and soil cover. In Ceylon, it yields heavily on well-manured soils, and produces hay of high nutritive value with a crude protein content higher than lucerne.

It is, however, not as palatable as lucerne, either fresh or dried. It is easily propagated by seeds (160,000 seeds/lb.). Seeds should be broadcast at 40 lb./acre and, in Ceylon, the first cut can be taken after two months. It is deep-rooted and competes well with grasses and other legumes. There are eight species in the Argentine flora but none is cultivated; some have forage value (e. g. *A. falcata* and *A. scabia*). Other species are *A. grandiflora*, *A. indica*, *A. vesiculata*, *A. virginica* and *A. viscidula*.

ALBIZZIA

Albizzia comprises about 25 species of trees and shrubs indigenous to tropical and sub-tropical Asia, Africa, America and Australia. They have practical value as shade and browse trees and for fodder and green manure. They are usually easily propagated by seed, but cuttings are also used. The species most commonly grown is *A. lebbek*. Its leaves and pods are used for fodder in India, Ceylon, Japan, tropical Africa, the West Indies, Brazil and many other countries. In Trinidad, the pods and beans are used as concentrates. In Brazil, the *lebbek* is often cut continuously and then behaves as a herbaceous plant. It is valuable as it keeps green even in dry periods. *A. lebbek* is also used as a shade tree. In Barbados it sometimes runs wild, becomes noxious and is difficult to eradicate because of its deep root system.

A. amara is common in Madras, India, where the cattle prefer it to other pasture and browse plants; *A. basaltica* occurs in eucalypt forests of Queensland and is abundant on sandy soils; it is a valuable fodder. *A. carbonaria* is found at medium altitudes in Colombia and Central America and is cultivated in Puerto Rico. *A. falcata* (= *A. moluccana*) is a tall, evergreen shade tree grown from seed in Indonesia, Indochina, Malaya and Ceylon; in Uganda, it is valued for its rapid growth even if rather short-lived.

A. fastigiata is promising in Ceylon but not in Uganda; *A. glabrescens* is sometimes used for providing shade in mature tea plantations in Nyasaland, where it also improves the nitrogen status of the soil. *A. lophantha* is proving successful on deep sandy soils in South Australia; *A. odoratissima* is used for fodder in Malaya, Ceylon and India; in Ceylon the branches of *A. procera* are eaten by elephants; in tropical Queensland it is a browse plant. *A. stipulata* (= *A. marginata*) is grown in many parts of India and Ceylon for its high-quality fodder; in Uganda and Indo-China it provides shade for coffee plantations, and in the Belgian Congo it is used for soil cover and green manure; it is propagated by seeds and cuttings. *A. sumatrana* is a valuable shade tree in Indonesia and is used for soil cover and green manure in the Belgian Congo.

ALYSICARPUS: Alyce Clovers

Alysicarpus vaginalis (alyce clover, one-leaved clover) is a native of Asia, whence it has spread to most tropical and sub-tropical countries, in which it is regarded as a good substitute for lucerne. Alyce clover is a perennial, but is often grown as a summer annual for hay, pasture, cover or green manure. It is a spreading and moderately branched plant attaining a height of about 3 ft. The leaves are unifoliolate, broadly oval, on short leaf stalks. It does not tolerate wet lands and makes poor growth on soils of low fertility. When used for green manure, the crop is allowed to volunteer for several years. As the seeds shatter profusely, seed harvesting is somewhat difficult. Alyce clover is very susceptible to root nematodes and can be grown only in fields which are comparatively free from these pests. In the Sudan it is considered suitable only for pastures and not as a short-term fodder plant. In the low wet zone of Ceylon, it is used in temporary pasture leys together with grasses (*Brachiaria distachya* and *Paspalum dilatatum*). In Malaya, it is a forage and cover legume yielding an excellent fodder of high feeding value. In Nicaragua, it produces two forage crops but only one seed crop a year. In Nigeria, it is a common weed of the late wet season, but is cut for fodder for tethered animals. 300,000 seeds/lb.; 10 to 20 lb. sown broadcast per acre.

Alysicarpus vaginalis var. *nummularifolius* is a West Indian variety of low, spreading habit with buds located in the root crown, which makes it an ideal pasture plant. It is used for this purpose in the West Indies and Queensland and has been tested in the United States. *A. longifolius*, a strong-growing annual from India, has been tested in Southern Rhodesia. It grows about 3 ft. high, is moderately leafy and capable of forming a thick cover, seeds abundantly, volunteers well and gives promise as an annual pasture legume.

Other wild species of minor importance are *A. glumaceus* in Central Africa and *A. rugosus* in North America, the Sudan, India and Queensland. In India *A. rugosus* is introduced into natural grassland areas where irrigation is supplemented by natural rainfall. It reseeds itself well and the stand is maintained in spite of indiscriminate grazing and cutting.

ANTHYLLIS: Kidney Vetch

Kidney vetch (*A. vulneraria*), also called Lady's Fingers or Woundswort, is a perennial herb from temperate parts of Europe, Asia and North Africa. It is deep-rooted and tufted, and has pinnate leaves ending in a big ovate leaflet. The flowers are usually yellow, borne in heads on comparatively long stalks. This drought

resistant species is adapted to poor, sandy or calcareous soils and is used for pasture in the northern temperate zone of Europe, Asia and North America. It grows quite well on sandy soils in certain parts of Argentina, but is little known in that country. It is propagated by seeds (175,000/lb.); 15 to 20 lb. are sown broadcast per acre, usually in mixture with pasture grasses.

The genus *Anthyllis* has 30 species, all perennial herbs or shrubs native to the same region as *A. vulneraria*. The others are not of any agricultural importance.

ARACHIS: Peanuts

The peanut or groundnut (*A. hypogaea*) belongs to this genus, which is native to Brazil and comprises about ten species. They are all low, tropical, annual or perennial herbs.

The peanut is a spreading, summer-annual herb, 10 to 20 inches high, with pinnate leaves and four broad, oval leaflets. The flowers are yellow with red striations, borne in the leaf axils. As soon as the corolla has dropped, the flower bends down, the ovary elongates, and forces the fruit into the soil where the pod, containing 1 to 3 seeds, ripens. The peanut is now widely grown in tropical and sub-tropical countries on an important commercial scale. Leading producers are India, China, Nigeria, French West Africa, Gambia, Uganda, South Africa (especially the Transvaal) and the United States. The large seeds have a high oil and protein content and are used for human consumption, the production of oil and concentrates for feeding, and many other purposes. The plant is also grown to some extent for hay, silage, pasture, soil cover and green manure. The peanut is very susceptible to frost and needs a hot climate for its development, with moderate rainfall or irrigation during the growing period and seed setting. Hot, dry weather is preferable during seed ripening. The crop prefers well-drained, fertile, sandy loams. As it is not aggressive to weeds, it should follow another cultivated crop. In the tropics the peanut is mostly grown as a main crop, but early varieties (90 to 100 days) make a second dry crop possible. There are a great number of varieties ranging from erect to creeping in growth habit and differing in earliness. Common varieties in the United States are Virginia Bunch and Spanish Bunch of the bunched growth type, and Dixie Runner, Virginia Runner, North Carolina Runner and Florida Runner of the runner type. Other widespread varieties are Jumbo, Tennessee White, White Spanish, Redskin and African. In South Africa, Virginia Bunch is the standard variety but others are also grown, e. g. Natal Common, Rustenburg and Jumbo. In the Sudan, Red Spanish Bunch is the best variety; Beladi Bunch and Barberton are not quite as good. In Queensland, Red Spanish and Virginia Bunch are grown extensively.

The peanut is resistant to eelworm and witchweed (*Striga* spp.). In most climates it often suffers from leafspot (*Cercospora*) and continuous cultivation results in attacks of root-rot (*Sclerotium rolfsii*). Peanuts should, therefore, be grown in rotation with crops such as maize, kaffir corn, millet, sunflower or sunn hemp. Rosette disease and wilt are also very important, and crown rot is transmitted with the seed but can be controlled with organic mercury compounds.

The seed being buried in the ground is harvested by combine harvesters with some difficulty. On loose soils the whole plant may be pulled up and most of the pods saved, but often potato diggers or special diggers are used. The plants are then dried on the ground and cured in stacks. In North America, the nuts are picked by special machines. Great care must be used in threshing seeds for sowing, as they are very susceptible to mechanical injury.

There are about 1,000 to 1,200 seeds to a pound of peanuts. In the United States, 32 to 48 lb. of unhulled or 20 to 30 lb. of hulled seeds are planted per acre, spaced about 30 × 12 inches. In India, 120 to 140 lb. of unhulled and 80 lb. of hulled seed are sometimes used to an acre, naturally with much smaller spacings. In Queensland, 20 to 25 lb. per acre are sown in rows 3 ft. apart.

Another species is *A. glabrata*, a prostrate, dwarf perennial used extensively in Brazil as a pasture plant on sandy loams. It produces small pods which cannot be harvested, and is propagated by rhizomes. This species has shown some promise in Florida.

There are four wild species in Argentina, *A. villosa*, *A. prostrata*, *A. marginata* (perennials) and *A. pusilla* (annual). All have some forage value in natural pastures, especially *A. prostrata*, which is glabrous and has long rhizomes. In Paraguay, *A. prostrata* is very common on waysides in mixtures with *Paspalum notatum*, *Cynodon dactylon*, *Desmodium canum*, *Axonopus compressus* and other herbs.

Wild perennial species of *Arachis* of possible pasture value in Australia were collected in the summer rainfall areas of South America in 1947/48.

ASTRAGALUS: Milk Vetches

Astragalus (loco, poison vetch and milk vetch) is a genus of mostly perennial herbs widely distributed in the temperate and arctic zones of the Northern Hemisphere. Only a few of the numerous species have any importance to agriculture. Most are unpalatable and toxic, some causing a disease called locoism.

Genge (*A. chinensis* = *A. sinicus*) * is a non-toxic, common green manure plant in rice fields of Japan and China, often sown when the rice is harvested and ploughed under in the following spring. It is a short-lived shrub with strong rhizomes and is fast growing. The *cicer* milk vetch (*A. cicer*) * is a European prostrate and pala-

table pasture plant, well-adapted for grass mixtures in shallow dry areas. It has also been grown in North America, but is of little importance. 20 to 25 lb. per acre are sown broadcast in the United States (130,000 seeds/lb.).

A. arenarius * and the sicklepod milk vetch (*A. falcatus*) are forage plants of Western Asia. The latter is used for forage in Russia and France and has also shown some promise in the United States. It is a prostrate annual, well-adapted to pastures on poor, dry land and is deep-rooted, long-lived and winter-hardy. When irrigated it produces high seed yields (130,000 seeds/lb.). 20 to 25 lb. per acre are sown broadcast in the United States. *A. abyssinicus* is an African short-lived, perennial herb of some promise in Kenya. *A. glycyphyllus* and *A. hypoglottis* are non-toxic species for calcareous soils of small importance in Europe and North America. *A. prolixus* is a wild forage plant in the Sudan. Species found useful in preventing soil erosion in the United States include *A. arrectus*, *A. cicer*, *A. davuricus*, *A. mortoni*, *A. rusbyi* and *A. verus*.

BAUHINIA

Bauhinia is a widely distributed, mostly tropical genus comprising a large number of trees and shrubs and some herbs, many important as fodder or browse plants: *B. malabarica* and *B. vahli* in south-eastern Asia, *B. reticulata* and *B. purpurea* in tropical Africa, *B. thonningii* in South Africa, *B. forficata* and *B. variegata* in tropical America, *B. monandra* in Fiji, and *B. carronii*, *B. hookeri* and *B. cunninghamii* in Australia.

CAJANUS: Pigeon Pea

The pigeon pea (*Cajanus cajan* = *C. indicus*) (or Congo pea, red gram, non-eye pea and alverja or alberga) is a native of the tropics in Africa, Asia and some South Sea Islands. It has been introduced to tropical America and Australia, and is one of the most common legumes of the sub-tropics and tropics. Pigeon pea is a short-lived, perennial, erect, coarse bush, sometimes grown as an annual. It is deep-rooted, has a very wide adaptability and grows especially well on semi-dry lands. It has trifoliolate leaves and either yellow (the early variety *flavus*) or yellow and red (the later variety *bicolor*) flowers, and reaches a height of 6 to 15 ft.

Pigeon peas are either grown as a pure crop or mixed with dryland cereals, and are sown in rows 3 to 4 ft. apart, thinned to 13 to 18 inches between plants. The seeds of the late, large-seeded varieties are used for human food and those of the early, small-seeded

varieties for fodder. Pods and leaves constitute an excellent fodder. This species is often used for hay and silage (with molasses), as a browse plant and for green manure, sometimes also for temporary shade. It is especially useful as a soil-improving plant, and is valued because it also provides a cash crop of grain. If cut for hay when the pods are well developed, the plants should be cut higher for each cut. If the plants are not cut back after seed harvest they will produce very little seed in the next crop.

According to Goerholt there are two methods of growing pigeon peas in Hawaii:

1. when seed has matured, the tops carrying the seed are cut off and turned under to produce a volunteer crop which is also turned under before sowing the next crop;
2. when pods are mature, the plants are topped to half length and the cut parts thrown on the ground between the rows where they will decay and give some volunteer plants. This is repeated every 6 months for 3 years.

This legume is particularly drought resistant, and even in an annual rainfall below 25 inches it can yield satisfactorily when other crops fail. Recorded yields of green matter vary from 18 to 35 tons, and seed from 20 to 30 bushels per acre. Although it is generally grown as a cultivated crop, the plant has been grown experimentally on poor soils in Queensland with little soil preparation and without fertilizer. Certain types are susceptible to frost, but winter-hardy strains have been selected.

In India, pigeon pea is often planted in the same rows as *Sorghum* at the beginning of the monsoon rains, in late June or July. The pigeon pea becomes well established but shows little growth for months, while the tillage operations used for the *Sorghum* serve for the legume as well. As the *Sorghum* develops, the shading of the ground reduces weed growth. When the *Sorghum* is cut in winter the pigeon pea continues its growth and matures a seed crop some months later.

Pigeon peas are attacked by fusarium wilt (*Corticium salmonicolor*) and root nematodes, caterpillars, seed-borers and grasshoppers. Some strains resistant to nematodes have been found in North America. 8 to 10 lb. are sown per acre in the United States in rows 3 to 4ft. apart (8,000 seeds/lb.). In Central America, 15 lb. per acre are sown for seed production, and double this for green manure. In East Bengal, 16 to 20 lb. per acre are sown broadcast.

CALOPOGONIUM

C. mucunoides (Calopo) is a vigorous, winding creeper from tropical South America, now widespread in localities with sufficient moisture all over the tropics. It is adapted to a wide range of soils.

In about 5 months it forms a dense mat of foliage 1 to 2 ft. high, and is perennial but not very long-lived. In Indochina, it is usually ploughed under at the beginning of the dry season as it would otherwise die out. It produces seeds profusely in 7 to 8 months from sowing, and reseeds itself freely. *Calopogonium* is usually propagated by seeds, but cuttings are used in Malaya. This plant is mainly used for soil cover and green manure, but in some countries the protein-rich foliage and seeds are used for fodder even if the hairy stems and leaves reduce the palatability. On the Atlantic coast of Nicaragua, it grows wild in the pastures, is most abundant from May to December, but dies out during the rest of the year. In Queensland, *Calopogonium* is sometimes planted with maize in order that animals may acquire a taste for it. It grows well in pastures with *Melinis minutiflora* and is useful in rejuvenating run-down pastures. It is not winter-hardy and does not withstand shade.

Calopogonium is especially recommended as a cover crop in new clearings, in coconut, coffee and young rubber plantations, but it does not stand the shade in old rubber groves. In Malaya, it is sometimes grown in mixture with *Centrosema* and *Pueraria*, which are more persistent, and in Brazil it is grown mixed with grasses such as *Chloris gayana*. In many countries it is used for the smothering of weeds and noxious grasses.

Three pounds of seed per acre (30,000 seeds/lb.) are recommended in Queensland, and 5 to 8 lb. per acre are sown in Malaya in rows 3 to 5 ft. apart. As the proportion of hard seeds is often high, they may require to be soaked in hot water overnight.

CANAVALIA: Jack Bean, Sword Bean

This tropical genus of about 25 species is composed of annual or perennial, erect or trailing herbs. The jack bean (*C. ensiformis*)* is a fast-growing, usually erect, sometimes twining annual 2 to 4 ft. high. It is often somewhat shrubby; in Indonesia, the runners may occasionally be 10 metres long. It is very deep-rooted and drought resistant but also tolerates shade. The leaves are odd-pinnate, trifoliolate and the leaflets ovate-elliptical, dark green and shiny, 10 to 20 cm. long. The light red-violet or white flowers are in racemes. The pods are linear and contain 8 to 30 seeds. The seeds are edible, but are somewhat poisonous when eaten in great quantities. This species grows wild in the West Indies, tropical Africa and parts of tropical India. It is cultivated for green manure and soil cover in South and Central America, Africa, India and Indonesia. The leaves drop both during the dry season and when the seed pods are ripening. Pods and seeds are used for human food. In the Sudan, where it is grown in heavier rainfall areas and under irrigation, the plant is also used for fodder, but the forage is only palatable when

dry. The large white, grey, brown or red seeds are sown singly 2 to 3 ft. apart, 8 lb. to the acre. In Central America, 35 lb. per acre are sown for seed production and 60 lb. for green manure.

A related species is the sword bean (*C. gladiata*) * which is used for the same purposes and is cultivated mainly in Japan, China, India and Indonesia. It is a twining herb. The seeds contain a toxic saponin.

CASSIA: Sennas

There are about 400 species of this genus in tropical and temperate zones, comprising trees, shrubs or herbs with pinnate leaves and nearly regular flowers. Many species are toxic and unpalatable, some are used for medicinal purposes and others are of some value as browse or cultivated fodder plants. Many are used as soil cover and for green manure. The sennas are usually not attacked by root nematodes.

C. didymobotrya * (the candelabra tree) is a small tree or shrub used for green manure in Malaya and Ceylon. In Uganda, it has been suggested for use as temporary shade in coffee plantations. It is browsed by cattle. *C. hirsuta* * is a vigorous bush used to some extent in Malaya, Indo-China and Uganda for soil cover, but it may also be cut and used for green manure. It is very susceptible to attacks of *Corticium salmonicolor*. *C. multijuga* is a browse plant in Brazil and a shade tree in Indonesia. It is propagated by seeds (70,000 seeds/lb.). *C. siamea* * is a tree or shrub used for fodder in Malaya and India (Orissa and Bombay), as hedges around paddocks in Nigeria, and for green manure in Cuba. This species grows well on lower altitudes in the Belgian Congo whereas *C. spectabilis* is more adapted to higher altitudes.

An indigenous species used for cattle food in semi-arid regions of Pernambuco, Brazil, is *C. ferruginea*. *C. leschenaultiana* * is a shrub native to India and the East Indies, where it is used for green manure and propagated by seeds (110,000 seeds/lb.). The Indian variety, *wallichiana*, is also recommended for the Belgian Congo. The yield of foliage is not high and it decomposes rapidly. *C. occidentalis* * (coffee senna) is a common weed in the south-eastern United States and Hawaii. This toxic herb or shrub is also found wild in many other countries. In Malaya and Indonesia, it is used to some extent as green manure, propagated by seeds.

C. pumila * is a creeping cover crop in Indochina, interplanted between rows of other crops to prevent soil erosion and maintain a loose and permeable top soil. It is propagated by cuttings but can reseed itself. The branches spread about 3 ft. but do not root readily. It is a half-erect plant and forms a carpet about 2 to 3 ft. high. Growth stops in winter and most plants die out.

C. tora * (sickle senna or wild senna) is an evil-smelling, unpalatable but probably non-toxic herb or shrub growing as a weed in warm climates in both the Old and New World. It has no root nodules but a beneficial effect on succeeding crops is claimed in the United States. It produces seed abundantly (22,000 seeds/lb.) and is sometimes used for green manure (Indonesia); it is then broadcast at 40 to 45 lb. of seed per acre. In Brazil (Pernambuco), it is recommended as a forage plant.

Other species are *C. artemisioides*, wild in New South Wales and eaten by livestock; *C. eremophila*, wild in New South Wales and Western Australia, and considered a useful fodder; *C. glauca* * used to some extent for soil cover in Uganda; *C. mimosoides* used for green manure in Indonesia and Indo-China, and growing wild in damp places or swamps or on heavy soils in south-east Asia and in Queensland, where it may be eaten by stock but is not very palatable; *C. patellaria* *, a shrub little used as soil cover and green manure in Indonesia; *C. sturtii*, grazed or pulled for fodder in South and West Australia.

A few herbs of the section *Chamaecrista* (*C. rotundifolia*, *C. serpens*, *C. repens* and *C. patellaria*) have forage value in Argentina and Paraguay. They grow in natural pastures in the north and north-east of Argentina.

CENTROSEMA

Two species, both native of South America, are cultivated throughout the tropics and sub-tropics. They are rather similar in type, creeping and twining perennial herbs with trifoliolate leaves and large flowers.

Their growth habit makes them excellent plants for soil cover and green manure, but they are unsuitable for tea or coffee plantations because they climb and cover the bushes. As they are non-toxic and palatable, they are also used as forage.

C. plumieri is grown as a soil cover and green manure in the tropics of Asia, Africa and America, being especially recommended for planting in clearings for rubber and in coconut groves. Whereas it is difficult to start in the shade of old rubber trees, it persists well under such conditions when once established. It is quick-growing, deep-rooted, drought resistant and has a strong tendency to climb. When trailing on the ground, seed setting is poor, but when supported its seed yield is good (Uganda). The plant is propagated by sowing 3 lb. of seed per acre in rows 3 ft. apart (2,500 seeds/lb.).

C. pubescens (centre) has been developed within recent times mainly as a tropical cover crop. It is a perennial, vine-like, very aggressive legume, which shows a marked tendency to climb, and

it forms a good cover over the surface of the ground within 4 to 6 months from seeding. It is very leafy and does not produce any woody growth even when 18 months old. This legume is drought resistant and persistent on good soils, does not thrive under wet conditions, but is easy to establish on poor arid soils without fertilizer; it is remarkably adaptable to dry conditions, even if it does use great quantities of water. When once established it also persists well in shade. *C. pubescens* is grazed by livestock when they become accustomed to it, and also makes good hay. If planted thinly and unshaded, it is a heavy seeder in areas with winter rainfall, but considerable difficulty is experienced in harvesting; the seed pods do not mature uniformly, and the crop is hard to mow. It will regenerate itself quite freely, and in Southern Rhodesia and Queensland, is recommended for pasture mixtures with grasses such as *Panicum maximum* and *Melinis minutiflora*. In Nigeria, it grows well with stargrass (*Cynodon plectostachyon*) in mixtures for both hay and pasture. Propagation is by seed (18,000 seeds/lb.); 4 to 5 lb. of seed are sown per acre in rows 3 ft. apart. The seeds require to be soaked in hot water before planting, since the percentage of hard seeds is usually high. In Malaya, where it is a common cover plant, seeds ripen within 9 to 12 months from sowing. In Uganda, seeds are also produced when the plant is trailing on the ground.

In India, *C. pubescens* is used for suppressing *Imperata cylindrica*.

CERATONIA: Carob Tree

Ceratonia siliqua (carob tree, locust bean, or St. John's bread) is a native of Syria and the northern coasts of Africa, but is now naturalized in many parts of the world. It has been cultivated since ancient times. In the United States, the carob has not proved adaptable to the humid section; it grows well with irrigation in the mild parts of the arid south-west but yields of beans have been comparatively light. It has been used as an ornamental tree in southern California and Arizona. It has shown great promise in semi-arid Argentina. It is a medium-sized evergreen tree which produces large quantities of pods of high nutritive value when used as feed for sheep, pigs, cattle and horses. Pigs eat them uncrushed, but they are often crushed and mixed with hay, grass or oats for other animals. The pods may be used for production of alcohol. The carob tree thrives on all soils if not too wet or too hard and close, and it is highly resistant to drought. It even stands light frosts. They are both monoecious or dioecious. Propagation is usually from seeds scarified in hot water. The young trees are mostly grafted with scions from productive female trees. Pods are produced from the 6th to 8th year. They are low in protein, but high in sugar.

CICER: Chick Pea

*Cicer arietinum** (chick pea, Garbanzo bean or gram) is an erect, shrubby annual 1½ to 2 ft. in height, native in West Asia. It is commonly grown in the Mediterranean area, around the Black Sea and in tropical Asia, in most parts of Africa, and in South and Central America. It is adapted to a tropical climate of moderate temperatures and rainfall and is sometimes grown under irrigation. In India, it is either grown as the sole crop of the year or succeeding an early crop (sometimes rice), or mixed with other crops. In South Africa, it is considered suitable as hay and produces seed for human consumption and poultry feed. In the Sudan, it is especially valuable for basins and river banks, sown in October-November; in Tanganyika, it is usually planted in May on heavy, but not water-logged, soils and is sometimes interplanted with cassava. It needs little rain and is not much affected by drought. The grain, young shoots and pods are used for human consumption, and the rest of the plant for fodder after threshing. The hay is somewhat toxic. The chick pea is also a good soil-renovating crop and can provide at the same time a cash crop of grain. The chick pea is susceptible to root nematodes, blight (*Ascochyta rabies*) and pod-borers. One pound contains 1,000 seeds; 20 to 30 lb. sown per acre in rows 3 to 4 ft. apart; in East Bengal, 30 to 40 lb. per acre are sown broadcast.

CLITORIA: Butterfly Pea

There are about thirty species in warm and temperate climates, growing as twining perennial herbs or shrubs; two are of some value to agriculture.

C. cajanifolia (= *C. laurifolia*) is a hardy, deep-rooted bush used mainly for green manure and for the prevention of erosion. The plant is unpalatable but the fleshy roots are eaten by pigs. In Ceylon, this species is used in clearings for rubber plantations and for hedges to prevent erosion and is cultivated up to 2,500 ft. above sea level. In Indonesia, it is used as green manure, especially on poor, eroded soils. In Uganda, it is considered as being slow to germinate and develop. *C. cajanifolia* is propagated by seeds (13,000 seeds/lb.).

C. ternatea (Kordofan pea) is a tall, slender climber probably originating in tropical Asia, but now widespread in both the Old and New Worlds, including Australia. It is mostly used as cover and for green manure, but the leaves and pods are grazed by livestock. It grows wild in many countries, and in Queensland is said to be difficult to eradicate because of its deep roots and heavy seeding habit; however, it does very well there under irrigation. In the Sudan, where it has been successful in field trials and free from diseases and pests, it produced dense cover when grown with a support crop, such as Sudan grass, sweet sorghum, and especially sunn hemp; it did not, however, yield as much as *Dolichos lablab* or velvet bean. It is considered a pasture plant of some promise in Kenya. In Barbados, *C. ternatea* is found in meadows with *Andropogon pertusus* and is very persistent; it is propagated by seeds and may be grown with support crops or staked with bamboos to facilitate hand-picking of the pods.

CORONILLA: Crown Vetch

Coronilla varia, crown vetch, is a creeping, perennial legume providing complete soil protection. It is particularly useful as a cover plant for roadsides and railroad banks, but has recently attracted interest in the United States as well suited for reclaiming and rebuilding worn-out farmland. Crown vetch is a European species but has been introduced, and is now widely spread, in the eastern United States. It is remarkably aggressive and chokes out weeds and grasses including cocksfoot, tall fescue and quack-grass. It is a deep-rooted, non-palatable perennial with an unusual ability to re-establish itself when ploughed out, e.g. for a corn crop. Seed production has now been started in North America. The seed must be hulled and scarified before sowing.

CROTALARIA

Crotalaria is a widespread tropical and sub-tropical genus with about 600 species. Native species occur in nearly every tropical country but the greatest number are found in Africa. They are erect annuals or short-lived perennial shrubs with coarse profusely-branched stems. The leaves are uni-or trifoliolate and leaflets linear to broad ovate. The plants are generally leafy, with showy, yellow flowers, and set seed freely. Seed production in south-east Asia and Indonesia is hampered by pod borers and can be recommended only in areas where these insects are absent. The seed colour varies from yellow to brown and black. This genus is usually self-fertilizing.

The *Crotolarias* are grown throughout the tropics, especially in India, mainly for green manure and soil cover. A. Burkart says that there are six wild species in Argentina, some widely dispersed, such as the weedy *C. incana* and *C. anagyroides*, which show promise as cover crops. The others are unimportant. Cultivated species imported from Florida have been tested for cover. They

grow very well and are also very successful in Paraguay: *C. juncea* grows well in Misiones. In Paraguay, in 1950, there were luxuriant test-plots of *C. juncea, C. grantiana, C. intermedia, C. usaramoensis, C. spectabilis* and *C. mucronata;* seeding was also very good. There were no parasites or diseases, but as forage they were a failure because cattle do not like them. As cover and fertility-restoring crops they were very good and tended to reseed themselves.

Many species are more or less toxic to farm animals but others may even be sufficiently palatable (*C. intermedia, C. striata* and *C. lanceolata*) to be used for fodder. Outstanding features of the *Crotalarias* are that they grow well on poor acid soils, are not (except *C. juncea*) attacked by root nematodes and grow very fast – all valuable characteristics in a green manure crop. As many hard seeds are produced, scarifying is recommended but seed inoculation is not needed in the United States. A great number of species are cultivated in different countries and more are being tested. Only a few can be mentioned here. They are mostly grown as catch crops in the off season, but sometimes as main crops for forage and seed. In some places (Tanganyika and Puerto Rico) they are also grown with or found volunteering in mixtures with grasses.

C. anagyroides is a non-toxic, perennial, tall, vigorous bush, native of Central and South America, grown there and in Ceylon, Malaya, Indochina, Indonesia and other countries. It is deep-rooted, drought resistant and rapid growing, and is used for cover and green manure in coffee and rubber plantings. It is readily attacked by *Corticium* and uses much water and nutrients. Like all *Crotalarias*, it is propagated by seeds (25,000 seeds/lb.); 20 to 30 lb. sown broadcast per acre or 6 to 10 lb. in rows 3 to 5 ft. apart.

C. grantiana * is an annual from Africa; although less coarse than most of this genus, it is more exacting in its growth requirements. Experiments in North and South America have shown it to be a promising cover crop, reseeding itself abundantly (150,000 seeds/lb.; 10 to 13 lb. sown broadcast per acre).

C. incana is a perennial bushy shrub, 5 to 6 ft. high, native of tropical Africa and America, non-toxic and one of the most palatable species even if rather coarse. It is used to some extent for fodder and cover, and is considered rather promising. The seed must be scarified before sowing (85,000 seeds/lb.; 15 to 18 lb. sown broadcast per acre).

C. intermedia is an African, non-poisonous, palatable annual which has recently attracted great interest in the United States and sub-tropical U.S.S.R. because of its great adaptability to soil and climatic conditions. It is now grown on large areas in Louisiana and elsewhere primarily for soil improvement, but also for grazing, hay and silage (100,000 seeds/lb.; 10 to 15 lb. sown broadcast per acre).

*C. juncea** (sunn hemp) is a widespread Indian species grown for fibre, soil cover, green manure and, to some extent, for forage.

It is a branched, erect, cross-fertilizing annual, 6 to 10 ft. high. It has elliptical lanceolate leaves and yellow flowers in terminal, open racemes. Pods are small, inflated and have stiff hairs.

This species is somewhat poisonous, but may nevertheless be used for forage in India, Ceylon, sub-tropical U. S. S. R. and parts of Africa. Russian investigations show that the hay has a protein content of 18 to 20 per cent. and the seeds from 30 to 60 per cent.; other analyses show considerably lower values. Young plants are not palatable, but dried leaves, husks and boiled seeds are fed to cattle in Ceylon. In Rhodesia, hay and seeds are not considered poisonous to pigs. In the U. S. S. R., the seed is fed to horses; in South Africa, sunn hemp is considered toxic to horses, but may be fed to cattle if it constitutes not more than 10 per cent. of the fodder. It is the fastest growing of all *Crotalarias*; although adapted to a hot climate it endures slight frost in spring or autumn. Vegetative growth is favoured by long days, but seed setting is then poor. In many regions two cuts can be taken if the first is made 10 to 12 inches from the ground.

In tropical climates, the seed production of this as of most *Crotalaria* species is hampered by attacks of pod borers. Diseases of sunn hemp in Northern Rhodesia include blight (*Colletotrichum lindemuthianum*), which often attacks the stem in the early stages and causes severe damage. Internal seed blight (*Nematospora coryli*) is also common; it is spread by a seed bug. Beetles of the genus *Exora* sometimes cause serious defoliation of sunn hemp.

When grown as a soil cover and green manure, 35 to 40 lb. are sown per acre (15,000 seeds/lb.). When grown for fibre or seed, this seed rate may be reduced. In Northern Rhodesia, sunn hemp is sown for green manure or hay at up to 50 lb./acre, but when grown for seed as little as 25 lb./acre may be sown. In East Bengal, seed rates are up to 80 lb. per acre. It is used to a great extent for green manure in rice and sugar cane fields, in orchards, pineapple plantings (Hawaii) and in coffee plantations (Brazil). It is often sown in rice fields between the rows before the rice is harvested (China); this may also be done in other crops.

C. lanceolata is a perennial, native of South Africa, rather common in the United States as a cover crop, where it is considered to be promising. It is non-poisonous but not very palatable, and has fine stems (170,000 seeds/lb.; 8 to 12 lb. sown broadcast per acre).

C. spectabilis * (= *C. sericea*) is an Old World poisonous, perennial species, especially adapted to sandy soils and grown both in the Eastern and Western hemispheres. It is a prolific seeder and volunteers well, as seeds shatter profusely. In the United States,

it has been replaced by *C. intermedia* and *C. mucronata*. (30.000 seeds/lb.; 20 to 30 lb. are sown broadcast per acre).

C. mucronata (= *C. striata*) is another Old World, non-poisonous but not very palatable erect shrub which has shown promise in several countries of the Americas, Africa and Asia. In Indochina, this wild species is widely adopted as a green manure on rice fields. It does not seem to be infested by *Corticium salmonicolor*. According to J. J. Ochse, the leaves and seeds contain a paralysing alkaloid, but seeds can be eaten after preparation. (75,000 seeds/lb.; 10 to 20 lb. sown broadcast per acre or 5 to 6 lb. in rows 5 ft. apart).

C. usaramoensis, Curara Pea, is a non-toxic Javanese species grown for cover and soil improvement in many tropical countries and adapted to most kinds of soil. It is not very rapid in growth. It is an erect, short-lived shrub used in tea, coffee and rubber plantations. It is cultivated in Australia (Queensland), Indonesia, Indo-China, Malaya, Ceylon, sub-tropical U.S.S.R., the Philippines, Central America, the West Indies and Argentina. If cut back twice, it may yield up to 20 tons of green matter per hectare (Indochina). During the dry season the stems dry out partially, but new shoots appear when the next rainy season starts. In order to make it more drought resistant and to get a quick growth when the rains start, it is preferable to cut it back to about 30 cm. towards the end of December (Indo-China). It produces abundant fruit but the pods are frequently attacked by insects. As *C. usaramoensis* may be attacked by *Corticium salmonicolor*, it is not recommended for rubber plantations. (160,000 seeds/lb.; 8 to 12 lb. sown broadcast per acre; 4 to 5 lb. in rows 5 ft. apart).

Other species are *C. agatifolia*, used in the Belgian Congo for cover and temporary shade in young coffee plantations; *C. alata*, * a short-lived shrubby plant which makes a low, dense cover when sown thickly; *C. brownei*, * a bush resembling *C. anagyroides* and *C. usaramoensis; C. candicans*, a much branched ornamental bush from India; *C. capensis*, * a branching shrub 4 to 5 ft. high from Africa; *C. ferruginea*, * a green manure plant from Java; *C. gorеensis*,* (Gambia Pea) a large, leafy perennial from tropical Africa grown for green manure in tobacco and sugar cane fields in Queensland, drought resistant and ratooning strongly if cut (seed rate 10 lb. per acre); *C. hirsuta*, a non-poisonous, promising pasture plant; *C. longirostrata*, * an upright plant from Central America, considered a valuable hay plant in Guatemala; protein content, digestibility and palatability compares favourably with lucerne, but it is toxic to man and perhaps also to animals; good for green manure; *C. polysperma*, * considered a good green manure in Indonesia; *C. retusa*, * a native of South Africa, 2 to 3 ft. high, unpalatable and toxic, but a good cover crop (French Equatorial Africa); *C. valentonii*, * a shrub promising as green manure in Indonesia.

Guar (*Cyamopsis psoralioides* = *C. tetragonolobus*) is an annual, erect herb, 3 to 6 ft. high with trifoliolate leaves and rose-coloured flowers. It resembles in some respects species of *Dolichos* and *Canavalia*, and is closely related to *Indigofera*. Its adaptation resembles that of the cowpea, and it is very drought resistant. Guar is much used in India, Pakistan, Indonesia and other eastern countries for fodder and green manure and is also grown as a vegetable. It has been tested in many countries (tropical Africa, North, Central and South America, Italy) and has been successfully introduced into the dry climate of south-western United States where it is grown for seed to produce a mucilage used in paper manufacture.

Guar is recommended as a forage plant in Argentina and for grain and forage in Sicily, where it is sown late in the summer in furrows and is irrigated. In Madras (India), and Texas, it is used as a green manure plant in rotation with cotton. Guar is not susceptible to cotton root rot. It is attacked by pests in the moist climate of Florida. In the tropics, the seeds (protein content 30 per cent.) are often fed to horses. In California, guar is often used as a summer cover crop. Guar is propagated by seeds (20,000 seeds/lb.). The seed rate in United States is 30 to 40 lb. per acre, sown broadcast, in India 10 lb. and in Sind up to 60 lb. per acre.

There are three recognised varieties in India, namely:

1. *Pardeshe*, growing to a height of 6 ft.
2. *Sotia*, growing to a height of 8 to 10 ft. This popular variety is grown with ginger in Gujarat to afford the necessary shade. The leaves are stripped off after the pods have been picked for use as a vegetable and are left on the ground as green manure.
3. *Deshi*. This variety is grown as a dry crop and reaches only a height of 4 ft. The seeds and foliage are used as cattle food and the green pods as vegetables. It is also grown as a green manure crop. When grown alone as a vegetable a spacing of 2 x 1 ft. is used but, as a green manure crop, it is drilled 1 ft. apart with about 15 lb. per acre. It is also grown in mixtures with sorghums and Kambu.

According to A. Chevalier other species are: *C. senegalensis*, a low annual herb growing wild in sub-arid regions of the northern Sudan and in Arabia, and is also found in south-west Africa. It grows during the rainy period and 2 to 3 months afterwards, and has some importance as a grazing plant. *C. stenophylla* is another similar, small annual, adapted to arid and sub-desert regions, found only south of the Sahara in the French Sudan.

CYTISUS

Only a few species of this genus of trees and shrubs have any importance as browse plants. The tagasaste or escabon, *C. prolifer*, and the gacia, *C. stenopetalus*, are highly appreciated as fodder plants in the Canary Islands and North Africa. They are drought resistant. The leafy branches are eagerly eaten by cattle. These species were also introduced to New Zealand where they have spread. The tagasaste has also spread in the western plains of New South Wales where it is useful fodder, but is very quickly eaten out by stock and requires a considerable degree of protection. Other species mentioned in New Zealand as eaten by sheep or cattle are *C. scoparius* and *C. monspessulanus*. These species are propagated by seeds.

DERRIS (= Deguelia)

Some species are used as shade trees and green manures in tea and coffee plantations in south-eastern Asia and Indonesia (*D. robusta*, *D. dalbergioides* and *D. microphylla*). They grow rapidly and stand strong winds. Propagation is by seeds. *D. microphylla* has been successful in Indo-China as a shade tree and green manure. It is rapid-growing and has drooping branches, stands cutting well and retains its leaves in the winter. *D. robusta* has similar characteristics. *Derris* is, of course, the source of an important insecticide.

DESMANTHUS

Dwarf Koa (*Desmanthus virgatus*) is an upright bush native of tropical and sub-tropical America. It is palatable, has an excellent growth and stands cutting and grazing. It is used for fodder and grazing at low elevations in Hawaii and Mauritius, and for green manure and soil cover in Indonesia. In the West Indies, *Desmanthus* species are browsed by cattle. *D. virgatus* and *D. depressus* grow in northern Argentina, but are not used there for forage.

DESMODIUM: Tick Clovers or Beggar Weeds

Desmodium (formerly *Meibomia*) is a large genus comprising about 200 species of perennial or annual herbs occurring mostly in the temperate and tropic regions of the Western Hemisphere, in Australia and tropical Africa. Species, such as *D. adscendens* and *D. triflorum*, are pan-tropical. The *Desmodium* species have stipillate, pinnately trifoliolate leaves and purple flowers in axillary or terminal racemes. They make excellent fodder and some are used as soil cover and green manure. A number of species are of some agricultural value in various countries. Most are propagated both by seeds and cuttings.

A. Burkart writes about *Desmodium:*

> "I do not know of a species being cultivated on any scale in South America. They are very useful elements of the native vegetation, but culture has not yet progressed for the following reason: (1) hard seeds difficult to germinate; (2) little resistance to grazing; (3) woodiness and so difficult to cut. Of course, I do not wish to speak against these promising plants, but there has been little progress in recent years. Experimental work must be greatly increased to find good species and strains suitable for cultivation, In the meantime, it is important to protect wild populations; they are so palatable that many species are literally being eliminated from pastures (e. g. *D. cuneatum* in north-east Argentina)".

D. adscendens is a wild vine in many tropical countries of both the Old and New World. As such, it is a valuable constituent of pastures, especially at higher altitudes and in wet localities. It is also found in clearings and along rivers where it covers the soil and kills the weeds. In Indo-China, Malaya, East and South Africa, it is planted in tea and coffee plantations as cover and for green manure. After flowering, the leaves drop and some vines die, but growth starts again with the rains, and covers the dead parts, which decompose. According to de Sornay, seeds are sown in flats in some parts of Africa and the seedlings later transplanted for the formation of cuttings; these are planted in the field 3 × 3 ft. apart.

D. barbatum and *D. discolor* grow wild in Brazil, Paraguay and sub-tropical Argentina and are there considered as good substitutes for lucerne in hot climates, on acid and calcium-deficient soils. In Florida *D. barbatum* has shown some promise as a pasture plant and is not attacked by root knot nematodes. In Hawaii, *D. discolor* is an erect perennial of value in semi-moist scrub pastures, in Southern Rhodesia it is tall and strong-growing and a promising fodder plant.

D. canum (= *D. supinum*) (creeping beggar weed, Kaimi a is clover) prostrate, semi-woody perennial, native of tropical America. It is tolerant to acid soils and adapted to a wet climate. It is said to stand continuous grazing well, and under such circumstances produces roots at the stem nodes. This species grows wild in Florida and Hawaii, where it has value as a pasture plant. It is now being tested in Queensland, where it has persisted in spite of severe competition with grasses, such as Guinea grass (*Panicum maximum*), and other legumes. Seed production is rather poor in Argentina. *D. capitatum* is a green manure and soil cover used in Malaya. *D. cephalotes*

is a bush indigenous in Ceylon and used there for green manure; it has a spreading growth habit and is a good seed producer. *D. cuneatum* is used for intercropping and green manure in Argentina.

D. diffusum has been introduced in natural grasslands in India where rainfall can be supplemented by irrigation. It reseeds itself freely, and it is said that the stand maintains itself in spite of indiscriminate grazing and cutting. Manuring with phosphates improves the legume and thus the grasslands as a whole. *D. gangeticum* is a pan-tropical annual fodder plant, also used in Java for green manure. *D. gyroides* is an erect-prostrate bush used in south-eastern Asia and Indonesia for green manure and soil cover. It is adapted to shade, stands pruning well and is recommended in Ceylon for rubber and tea plantations up to an altitude of 2,500 ft. Sometimes it is used for temporary shade in young coffee plantations. It is propagated by seeds and cuttings (102,000 seeds/lb.).

D. distortum is a forage legume growing wild in Central America. The plant is herbaceous, perennial and grows to a height of from 6 to 8 ft. It should be cut back repeatedly to a height of about 1 ft. The loppings can be fed directly to cattle, goats and poultry or a hay meal may be prepared for feeding poultry. It has been successfully tested in Ceylon and the Philippines. In the last-mentioned country it is considered an ideal forage for goats since intestinal worm infection is reduced to a minimum when goats browse on this shrub.

D. heterophyllum, a perennial prostrate herb is said (with *D. triflorum*, *D. tortuosum* and *Mimosa pudica*) in Fijian pastures to replace the clovers and trefoils of temperate zones. In Indo-China, it continues growing far into the winter, makes a rather thick mat of foliage but does not prevent weeds from encroaching. In Queensland, *D. heterophyllum* forms a close sward which may be useful in combination with prostrate grasses (seeded at 3 lb. per acre); it is palatable and stands close grazing. In Ceylon, it is considered a good pasture plant, but is somewhat difficult to control.

D. limense var. *sandwicense* is palatable to cattle in Ceylon and stands grazing well; it is useful as a forage crop either alone or in mixture.

D. nicaraguense is a drought resistant, green fodder plant of Central America, also tested in South America. In El Salvador, it is usually clipped at a height of 2 to 3 ft., and provides good food for the dry season. There, it is considered the best perennial legume, but is killed out by too close grazing; it can be grown up to 1,100 ft. above sea level. It is propagated by seeds or cuttings.

D. ovalifolium is a trailing cover plant in Ceylon, considered specially good in rubber plantations since it thrives even in rather dense shade.

D. salicifolium is a perennial recommended for permanent fodder plots in swamps in Sierra Leone. *D. scorpiurus* is a wild species common in El Salvador and Nicaragua. It is propagated by seeds or cuttings, and is recommended for upland pastures mixed with carpet grass (*Axonopus affinis*). It was introduced into Queensland from the Pacific Islands about 20 years ago and has been found to be palatable to stock, to recover quickly after grazing and to be a prolific seeder. The pods are covered with minute hairs and stick readily to the hair of animals, disseminating the plant. Samoan clover, as it is called in Australia, thrives in areas of abundant rainfall under tropical conditions. It is sometimes grown in mixture with grasses (*Panicum maximum* and *Paspalum scrobiculatum*). A seeding rate of 1 to 2 lb. per acre is recommended. It is promising in Nigeria where it remains green practically throughout the dry season. *D. spirale* is as indigenous plant used for cattle feed in Brazil and is especially recommended for semi-arid zones of Pernambuco.

D. tortuosum (= *D. purpureum*) (tall tick clover, Florida beggar weed) is an upright herbaceous annual-perennial (4 to 7 ft.), native to tropical and sub-tropical America, which has spread over great parts of America (from the United States to Argentina), Hawaii and Africa. It is used for pasture, hay, soil cover and green manure. It is propagated by seeds (420,000 seeds/lb., 8 to 10 lb. sown broadcast per acre) and volunteers well in pastures. It is recommended for cultivation in the south-eastern United States, Central and South America, Southern Rhodesia and Italy. This species grows abundantly throughout Nicaragua and is recommended for cultivation there; if planted in rows 1 yard apart it rapidly covers the ground completely and does not allow weeds to become established. In December, the leaves wither and the plants remain in this condition until the first rains, when new sprouts appear. It is especially recommended to be made into hay to be fed to livestock when pasturage is short. *D. triflorum* is a small, creeping, perennial mat-plant producing good fodder in hot climates. It recovers well after grazing or cutting. It is found in most tropical countries and is sometimes considered a bad weed in India. In Malaya, Indonesia and Ceylon, it is often planted as a cover plant in rubber plantations and persists also under old rubber trees. It should not, however, be used in tea plantations as it climbs upon the bushes. In a wild state, it is of value in many countries as a pasture plant.

D. umbellatum (horse bush) is a fodder plant in the coastlands of Queensland and the Northern Territory of Australia; it should be tried more especially on coasts for controlling bank erosion. *D. uncinatum* (Spanish clover) is a spreading perennial native to tropical America. It grows well with grasses such as Kikuyu (*Pennisetum clandestinum*), has a large but shallow root system, and therefore thrives best in wet lowland. It has strong, upright

stems when uncut, but spreads and roots at the stem nodes when cut. It has considerable importance in pastures over much of South America, especially on heavy soils, is very successful in Hawaii and shows promise for coastal Queensland. *D. wightii* is a perennial herb, 3 to 4 ft. high, adapted to tropical low country.

DOLICHOS

This genus is closely related to *Vigna* and *Stizolobium*, and many species have been referred by some authors to one genus or the other. *Dolichos* species are tropical annuals or perennials, herbs or low shrubs, usually prostrate or partly erect and normally having long runners. They are mostly natives of tropical Africa and Asia.

D. biflorus (horse gram or Kulthi bean) is a twining, succulent annual herb 1 to 1 1/2 ft. high, extensively grown as a pulse in southern India. The seeds are used as concentrated food for cattle. It is grown as a dry crop under a moderate rainfall (not more than 35 inches), often mixed with cereals (sorghum). It is very drought resistant and hence suited to sandy and shallow soils; the crop grows well on all types of soil provided they are not very alkaline. This species is also used for forage, soil cover and green manure, and is cultivated in Malaya, Mauritius, Sierra Leone, Transvaal and the West Indies. It grows wild in the eucalyptus forests of Queensland.

D. bulbosus (= *Pachyrrhizus angulatus*)* (Manioc bean or Yam bean) is a native of the Philippines but is also grown in Indonesia, India, Mexico and other tropical countries. It has perennial tubers but the stems are annual. It has trifoliolate, broad leaves, bluish-violet flowers in clusters, and spreads and covers the ground rapidly. The tubers are used for food, the vines for fodder and the seeds only for propagation, since they are toxic to cattle.

D. falcatus is a perennial, bulk-producing, twining species considered of promise in Kenya.

D. lablab (= *Lablab vulgaris*) * (hyacinth bean, bonavist, lablab, Egyptian bean) is a widely cultivated perennial, also grown as an annual in South and Central America, East and West Indies, China and large areas in Africa. It is a robust twiner, in Asia very often cultivated as a garden crop. It has a similar adaptation to the climate as the cowpea and is grown in Africa and Asia primarily for the edible seeds, but also for hay, silage and green manure. In India, it is grown mixed with *Eleusine* where the rainfall is about 25 to 35 inches. In the Sudan, it is found on flooded land or steep

river banks and is either grown alone or with sorghum or maize; it is then cut twice, or livestock are tethered or herded in the field. Later a crop of mature beans may be taken and finally the field is grazed. It is grown in rotation with sorghum and wheat in the riverain areas or with cotton in the Gezira. A bacterial disease (*Xanthomonas phaseoli*), which appears in humid weather, causes severe defoliation; if grown mixed with *Phaseolus trilobus*, the attacks of this disease are reduced. A crop of 5 to 10 tons of fodder per acre may be obtained. In Argentina, there are no pests or diseases of this bean, much to its advantage over varieties of *Phaseolus vulgaris*. In El Salvador, it is sown as green manure after maize has been harvested, and remains green throughout the dry season (6 months). Unripe pods and ripe seeds can be fed to stock, though some forms may contain cyanogenetic glucosides (1,400 seeds/lb.). From 20 to 25 lb. are sown per acre in rows 3 to 4 ft. apart.

ERYTHRINA: Coral Trees

There are about 50 species of *Erythrina*, mostly woody and spiny plants with showy flowers, in temperate and tropical regions throughout the world. Many are used as shade trees in the tropics, and some also for browsing and lopping. In Indonesia, *E. crassifolia* (dadap solo) and *E. subumbrans* (= *E. lithosperma*) (dadap serap) are common shade trees in tea, coffee and cocoa plantations. The former is propagated by cuttings, the latter by seeds or cuttings. *E. subumbrans* grows wild in Java in moist localities up to 4,500 ft., and is also common in Indo-China, Southern India, Ceylon and St. Helena; it can be regularly lopped for fodder.

Species used in Uganda as shade trees are *E. micropterys*, *E. glauca*, *E. umbrosa*, *E. velutina* and *E. indica*. They are attacked by stem borers. *E. indica* is a common shade tree in Bombay, Madya Pradesh and Bihar, India. Some species are used in Venezuela for shading cacao. *E. berteroana*, Bucare, is browsed on pastures in Trinidad.

GALEGA : Goat's Rue

Three species in Southern Europe and Western Asia are bushy, erect, perennial herbs, deep-rooted, too coarse for hay, somewhat poisonous, but of high nutritive value. Goat's rue (*Galega officinalis*) * grows 2 to 3 ft. high and has very low winter-hardiness. *G. orientalis* * is more hardy. *G. officinalis* is adapted to acid soil,

poor in organic matter, either hard or clayish, or sandy. It is used to some extent for soil improvement and as a bee-plant in southern Europe and Germany. In Italy, 20 to 35 lb. of seed per acre are sown in the spring and the plants are ploughed under in the autumn or early next spring. It is grown in rotation with maize. Goat's rue has a limited use as a forage plant because of its bitter taste and as it contains a poisonous alkaloid. If it is cut early, palatable silage can be prepared. In Argentina and central Chile, goat's rue has become a weed of low, rich and humid soils, where it is not eaten by cattle.

GLEDITSCHIA: Honey Locust or Sweet Locust

This genus comprises large deciduous trees grown for shade or as hedges in North and South America, tropical and sub-tropical Africa, eastern and central Asia and Australia. The honey locust (*G. triacanthos*), known in Argentina as "acacia negra", is also a fodder tree producing large pods rich in sugar. It has wide adaptability and resistance to frost and drought. As it produces many suckers, it is also used for erosion control. This tree can be grown easily from seeds scarified in hot water, but budding and grafting are also practised. The trees bear pods from the fourth and fifth year, and when fully grown may produce as much as 500 lb. of pods per tree. There is great interest in this fodder tree in South Africa. In Argentina, the variety *inermis* has been selected and is now widely propagated by seedsmen.

GLIRICIDIA

This genus comprises six to eight species in Cuba, Mexico and South America. *G. maculata* (= *G. sepium*) is a medium-sized, quick-growing tree used for shade and green manure in tea, coffee and cocoa plantations in many countries (Indonesia, Malaya, Indo-China, Ceylon, Uganda, Zanzibar, West Indies, Venezuela). It is mostly propagated by cuttings but also by seeds in some places (3,000 seeds/lb.). In Uganda, it is difficult to obtain a high crown on the tree and the foliage is too dense; in Zanzibar and Nicaragua, it is not always effective as a shade tree because the leaves are shed in hot weather. The foliage has good feeding value and is fed in Malaya and Ceylon. In Trinidad, the tree is a browse plant in pastures. In the British West Indies, it is palatable to cattle and other livestock. There, *G. maculata* is often planted as a low hedge

through grassfields and along the borders to provide protein-rich forage and vegetable matter for mulching. The hedges are kept at a height of 3 to 4 ft. and produce large quantities of loppings during the rainy season. They are trimmed at intervals of 6 to 8 weeks and the leaves are fed either fresh or dried and ground to a meal. The latter contain about 22 per cent. protein.

There has been difficulty in many countries in providing green manure, as such crops had to be raised in the fallow period when there is a lack of irrigation water, and cattle trespass on the land. Those difficulties have been overcome in Madras, India, by raising quick-growing leguminous shrubs like *Gliricidia maculata* on the bigger bunds and *Sesbania speciosa* in the paddy fields along the margins of the bunds. They grow to heights beyond the reach of cattle and goats within 3 or 4 months, and there is no adverse shade or root effect on the paddy crops. In an average paddy field, there are about 500 yards of bunds, some of which can be left without planting for use as footpaths. *Gliricidia* stands repeated lopping and supplies about 20 lb. of leaves per plant within 18 months.

GLYCINE: Soyabeans

The soyabean has had many scientific names (*Dolichos soja*, *Glycine soya*, *G. hispida* and *Soja max*), but throughout this publication we have used the modern name *Glycine max*. It is a summer annual herb, native of south-east Asia. It is usually erect (1 to 4 ft.), but some varieties are more or less twining, somewhat resembling the ordinary field bean. The whole plant is covered by fine brown or grey hairs. The trifoliolate leaves vary greatly in size and shape. As a rule they are dropped before the seeds are mature. The white or purple inconspicuous, self-fertile flowers are borne in the axils of the leaves and the pods contain from one to four seeds. These vary in colour (yellow, green, brown, black or mottled) and size (1,500 to 10,000 seeds/lb.). The seed rate for sowing consequently varies a great deal. Soyabeans having 2,500 seeds/lb. are sown broadcast at 45 to 60 lb. per acre or 20 to 30 lb. are drilled in rows 25 to 35 inches apart in the United States. The soyabean needs warm but not too hot summers for its development and can be grown on most types of soil, even if poor. It thrives best in a somewhat moist loose soil, but is also drought resistant. It responds well to potash, phosphate and farmyard manure.

Soyabeans are chiefly cultivated for the seeds, which are used for human consumption, the production of concentrates for farm animals and of oil, and in the manufacture of many other valuable materials. The soyabean plant is also used for hay, silage, pasture,

cover and green manure. In Asia, the seed is mostly harvested by pulling the whole plant; elsewhere, it is harvested with windrowers, binders or combines; special varieties have been developed for this purpose which carry the pods higher on the stems than the oriental types. There are innumerable varieties and strains adapted to different growing conditions and purposes of cultivation.

The soyabean is grown extensively in Manchuria, but China, Korea and Japan are also large producers and the crop is grown in the Philippines, Siam, India and the East Indies. Ancient Chinese records show that it is one of the oldest crops grown by man. Early introductions into the United States led to the cultivation of 50,000 acres by 1910; by exploration in northern China, Manchuria and Japan some hundreds of forms were introduced between 1929 and 1931. The spectacular development in America has occurred chiefly in the Corn Belt and was made possible by exploration followed by active commercialization. In general, the distribution tends to follow roughly that of maize. More than 200 million bushels were grown in the United States in 1946, and there are more than 150 processing plants.

Some 20 years ago, most of the American crop was used for hay but now only a small percentage is so used. In South Africa, soyabeans are commonly cut for hay, especially in districts too moist for the cowpea. Much seed is also harvested there, since non-shattering varieties have been bred. The cultivation of soyabeans is intensive in Natal and parts of the Transvaal. It is grown in rotation with maize and other main crops, and sometimes as a catch-crop in warmer areas. Soyabeans are also ensiled together with cereals. The soyabean is of little importance in Argentina mainly because of the lack of adapted varieties. In the north where lucerne does not grow, the soyabean has greater importance as forage. In Uruguay and Corrientes, it is successfully used for special purposes, e. g., as summer and autumn pasture for young lambs; lambs on soya pasture do not lose weight with the change from a milk to a pasture regime. The variety Laredo (black-seeded) and a yellow-seeded one are best adapted; both are erect types.

Great damage is sometimes done by eelworms and bacterial blight (*Bacterium glycineum* and *B. sojae*), anthracnose (*Glomerella glycines*) and other fungi.

Below we give a list of new soyabean varieties which have come into prominence in the United States during the period 1938-1949 and their classification in regard to earliness. Soyabean varieties have been classified in nine main groups by the United States Regional Soyabean Laboratory and co-operating agencies. Varieties in groups O and I are adapted to the northern states, group VIII to the Gulf Coast region, and the others are intermediate.

Table XXXIV.

Variety	Use
Group O	
Sioux	Green vegetable
Montreal Manchu	Beans
Flambeau	,,
Kagon	,,
Kabott	,,
Pagoda	,,
Pridesoy	,,
Sac	Green vegetable
Ottawa Mandarin	,,
Capital	,,
Group I	
Monroe	Beans
Earlyana	,,
Manchukota	,,
Ontario	,,
Cayuga	Hay
Group II	
Harman	Beans
Richland	,,
Bavender Special	,,
Hawkeye	,,
Korean	,,
Granger	,,
Seneca	Beans and Hay
Mendota	Green vegetables
Group III	
Adams	Beans
Lincoln	,,
Chief	,,
Viking	,,
Pennsoy	,,
Mingo	,,
Scioto	,,
Group IV	
Pakota	Beans
Gibson	,,
Boone	,,
Wabash	,,
Group V	
S 100	Beans
Group VI	
Ogden	Beans
Rose Non-Pop	,,
Dortchsoy No. 2	,,
Arksoy 2913	,,
Hale Ogden No. 12	,,
Ralsoy	,,
Group VII	
Volstate	Beans
Roanoke	,,
C. N. S.	,,
Palmetto	Hay and beans
Tanner	Hay
Group VIII	
Pelican	Beans and hay
Acadian	,,
Avoyelles	Hay and green manure
Seminole	Green vegetables and beans
La. Green	Beans and hay
Gatan	Hay
Yelnando	Hay and beans
J. W. 75	Beans

Hay varieties in the United States include:

Northern States (in order of earliness): (*a*) Wisconsin Black, Cayuga, Wilson, Peking, Kingwa, Ebony and Virginia.

Southern States: (*b*) Laredo, Tanner, Hay seed, Palmetto, Gatan, Otootan and Avoyelles. They make tall, viny growth and often lodge badly. Their seed yield is comparatively low but is compensated by small seed size. For hay, they are planted in rows 24 to 30 inches apart with 12 to 18 seeds per foot. Hay is cut when seeds are half-developed

and leaves have not begun to drop. Harvesting may be done by a mowing machine followed by drying in the swath, or by a binder with subsequent drying in shocks.

Soyabean varieties from the United States have been successful in other countries. Thus, in India, these varieties mature very early in about 60 days. In regions where unirrigated wheat is grown, the land is generally kept fallow in summer and wheat is again sown in October. If at the outbreak of the monsoon American soyabeans are sown in the middle of June, they can be taken for fodder or ploughed in at the end of July, or for grain in the middle of August. The rainfall up to September can be conserved and utilized for growing wheat. In East Bengal, the following varieties are distributed by the government: K-16, K-30, Barmeli and Large White.

Varieties commonly grown in Nigeria are: Malayan, Benares, Trinidad, Dixie, Acadian and Mamloxi.

The soyabean genus contains about 40 species, but few apart from *Glycine max* are of any importance in agriculture. Most are perennial twining vines in the tropics of Africa, Asia and Australia. A close relative to the cultivated soyabean grows wild throughout much of eastern Asia. This species (*G. ussuriensis*) is procumbent, has fine, twiny stems and small, narrow leaflets. The seeds are sooty-black in colour and range from 1 to 2 gr. per 100 seeds.

The most widespread species is *G. javanica* (East Indies, Manchuria, tropical Asia, Abyssinia, tropical East Africa and parts of South Africa). In Queensland, this perennial slender species is an outstanding legume among more recent introductions, possessing all the characteristics of a good pasture species, since it makes good growth, is palatable and seeds prolifically. It has also shown great promise in Paraguay. In Africa, it is an excellent substitute for kudzu with similar climatic requirements. It does not yield so much, but sets seeds readily and is therefore easier to propagate. It is non-poisonous, palatable to stock and high in nutritive value. It can be grown mixed with grasses such as *Setaria sphacelata*, elephant grass (*Pennisetum purpureum*), Guinea grass (*Panicum maximum*) and molasses grass (*Melinis minutiflora*).

G. falcata is a herb occuring in the semi-arid grasslands of Queensland and is considered a promising pasture plant. It produces underground pods.

HEDYSARUM: Sulla

Hedysarum coronarium is a perennial, rather deep-rooted herb with erect-prostrate, simple or branching, fibrous stems about 4 to 5 ft. high. The leaves are pinnatifid with 3 to 7 pairs of oval or round leaflets. The purple flowers appear on erect racemes. The pods, consisting of 3 to 5 elliptical or roundish segments, have a yellow, thorny surface which turns brown at maturity. There are

many local strains of sulla in Italy and Spain, also a white-flowered variety, smaller and more cold resistant than the others.

Sulla thrives in a warm but not tropical climate with mild winters. It is drought resistant but also grows well under irrigation. It grows best on deep, rich, calcareous soils, but also gives good results on poor, compact soils so long as they contain lime; its deep roots utilize the lime in the subsoil. It cannot be grown on acid or saline soils or in stagnant water. Sulla is not too demanding on minerals, but responds well to both artificial and natural manures.

The crop is of great agricultural importance in southern Italy, Sardinia, Sicily, Malta, parts of Spain, North Africa and Greece as a green fodder and hay crop. It is grown to a lesser extent in other Mediterranean countries where winter rains are ample. It has been recommended for Ethiopia, and is valued as green fodder in regions of Australia with a Mediterranean climate. Sulla makes very specialized demands on the environment; whereas it may be of great importance in one region it will be quite unsuccessful in other apparently similar regions.

Sulla is either sown alone, with cereals, or sometimes in mixtures with other legumes such as lupins or red clover and used for pasture. Seed rates per acre are 70 to 130 lb. of unhulled or 18 to 36 lb. of hulled seed depending on climate and soil. The seed is usually broadcast and harrowed in. When sulla grows widely spaced the stems become thick (up to 3/8 inch in diameter) and difficult to cut and dry for hay. It therefore requires to be grown in dense stands. The leaves adhere well to the stems when dry, an advantage over lucerne when making hay.

Seeding time is usually November to February depending upon the climate. The crop grows slowly through the winter but develops quickly in spring. A stand will generally persist 2 to 3 years. Several cuts can be taken per year, but when grown for seed only a very early cut or no cut at all can be taken before the pods turn brown. When hot dry weather prevails during seed ripening, the proportion of hard seeds is high. This can be remedied by hot water treatment (140° to 167° F. for 1 minute). Seed production is best undertaken in moist regions. There are about 100,000 seeds/lb.

Sulla yields up to 50 tons of green matter per acre under irrigation in the second growing year. Non-irrigated sulla may yield 6 to 16 tons per acre. The nutritive value is similar to that of red clover. Seed yields are about 250 lb. per acre.

INDIGOFERA: Indigo

This genus comprises about 300 species found in all tropical regions and as far down as the Cape in Africa. They are usually shrubs or perennial herbs. The leaves are silky or hairy, usually odd-pinnate, rarely digitate or simple. Flowers are purple, rose

or white and the pods usually have thin partitions. Many species have agricultural value as fodder, cover or green manure, and the two species, *I. suffruticosa* and *I. tinctoria,* were early known as sources of indigo.

I. arenaria is a desert plant grazed by camels in the Sudan. It has also shown promise in Ceylon.

I. arrecta * is an erect, woody bush, stands limited pruning well, but is not very long-lived when continuously pruned. It is propagated by seeds. In Indonesia, India and Ceylon, it is used for cover and green manure. In India, it is specially recommended before cotton in rotations, and in Ceylon, it is used in new rubber clearings. It also occurs in Equatorial Africa but is little used.

Trailing indigo, *I. endecaphylla,* * is a drought resistant, perennial, creeping herb with a strong root system. In some countries, e.g., Indo-China, Hawaii and Queensland, it produces seeds freely, but seed production is generally poor and propagation is done, partly or exclusively, by cuttings. There are about 200,000 seeds to a pound. In Trinidad, it is to a small extent used as an orchard cover, but does not withstand weed competition as successfully as *Pueraria* and *Stylosanthes.* In Malaya, cuttings 9 in. long are planted 2 × 2 ft. apart, in Puerto Rico 4 × 4 ft. apart. Although trailing indigo is sometimes toxic to livestock, it is still used in most tropical countries for pasture or fodder in mixtures with grasses, and for cover or green manure. From Southern Rhodesia it is reported that its palatability is rather low. It thrives from sea level to an altitude of several thousand feet. It is suited for growing in coffee, tea and new rubber plantations, but not in old rubber. It may grow well in pastures with grasses, such as *Paspalum dilatatum, Pennisetum purpureum* and *Panicum maximum.* In Hawaii, it is tolerant to somewhat acid and phosphorus-deficient soils, and in Trinidad, it has done well on the notoriously unproductive Caroni Terrace soils.

Hairy indigo (*I. hirsuta*)* is an erect-prostrate, climbing annual, producing heavy foliage on fine stems, which in later stages of development grow rather coarse. This plant grows wild in most warm countries and is often an important constituent of pastures. In many countries, such as the south-eastern United States and Indonesia, it is cultivated as a cover and green manure, but it also yields good quality forage which can be used for hay and pasture. When hairy indigo is grown pure, it has to be cut early to prevent it from becoming coarse. It thrives on moderately poor, sandy soils with little lime. In the United States, no inoculation is needed; it is resistant to root-knot and reasonably free from diseases and insect pests. Hairy indigo is a good seed producer (about 200,000 seeds/lb.) and in the United States 8 to 10 lb. are sown broadcast per acre. It volunteers readily. An early strain developed in the United

States has extended the growing area considerably. In Southern Rhodesia, there is a perennial type which is rather slow in growth and unpalatable; in Ceylon, it grows freely in the dry zone and seeds itself very well.

I. hirsuta * grows wild in Queensland on loose, sandy soils; although considered to be toxic, it is still used for fodder.

Another wild species (*I. linifolia*) in that country is valuable as sheep food. A small herb (*I. ovina*) is browsed by sheep and in Cape Province in South Africa, whereas *I. pauciflora* is eaten by camels. *I. pilosa* is a favourite with the peasant farmer of Ceylon for green manuring of paddy, and is recommended for soil conservation in the United States. It grows flat on the surface and competes with grasses, is fairly palatable and non-toxic and makes heavy growth on sandy soils. In Paraguay, *I. hirsuta* and *I. pilosa* are recommended as cover and green manures, where they compete with weeds. In Southern Rhodesia and Kenya, *I. retroflexa* (= *I. subulata*) is considered promising as a forage crop. It is a perennial 2 to 3 ft. high, resistant to drought and light frosts.

I. suffruticosa * is an erect shrub, 3 to 6 ft. high, a native of tropical America, used to some extent for cover and green manure in Indonesia and Ceylon. In Hawaii, it has some value as pasture. Propagation is by seeds. *I. sumatrana* * is another shrub used for cover and green manure mainly in Indonesia, but also in Central America. It is propagated by seeds (150,000 seeds/lb.). *I. tinctoria** is similar to *I. suffruticosa* and these two species are the main sources of indigo. *I. tinctoria* originated in India but is now pan-tropical. It is unpalatable, but is sometimes used for cover and green manure.

I. teysmanii was introduced from Indo-China to Ceylon. There it reaches a height of 21 ft. in one year and is considered very promising as a shade tree for tea, coffe or cacao and for regeneration of land subject to shifting cultivation.

INGA

This is a large genus of trees and shrubs found in tropical America. Several species are of great agricultural importance, being considered the best shade trees for coffee.

I. dulcis, of Mexican origin, has been introduced into India, where it is used as a hedge or roadside shade plant in Uttar Pradesh, Bengal and Bombay. The edible fruit contains seeds surrounded by a sweet pulp. *I. edulis* is considered the best species for shade in coffee plantations in Colombia. The roots do not exhaust the soil and the tree develops a crown, shading an area of about 36 ft. in diameter. Seeds are sown in nurseries, and seedlings are trans-

planted about 26 ft. apart. This species is also used for shade in Venezuela, El Salvador, New Caledonia and Puerto Rico.

Other species used for shade are *I. inga* and *I. laurina* in Puerto Rico, *I. spectabilis* (syn. *I. fulgens*) in Panama and Costa Rica, and *I. spuria* in Colombia.

LATHYRUS

The genus comprises more than 100 species, annual or perennial herbs, mostly native to the Northern Hemisphere; a few are found in South America. Only a few species have any importance in agriculture. Many are more or less toxic to farm animals, especially as far as the seeds are concerned.

The vetchling or flat pod pea vine, *L. cicera*,* is an annual-perennial, succulent, drought resistant herb in the Mediterranean region. In southern Europe, it is often grown as a green manure plant or for fodder, in spite of the fact that it is somewhat poisonous. The seeds are non-toxic. It has also shown promise in the United States, Argentina, and for light lands in Portugal, incapable of producing spring cultures, or where late ploughing of green manure is immaterial. It is propagated by seeds (8,000 seeds/lb.); 60 to 70 lb. are sown broadcast per acre.

The rough pea (Caley pea or singletary pea) *L. hirsutus*,* is a Mediterranean annual with long weak stems about 1 1/2 ft. high, popular in the southern third of the United States for pasture, hay, winter cover and soil improvement. The leaves have only one pair of long, narrow leaflets and terminate with a coiled tendril. The seeds are toxic. The rough pea prefers lime, but also grows well on acid soils and under rather wet conditions. In South Carolina, it grows well with Bahia grass (*Paspalum notatum*) on sandy soils where clovers are not adapted. The rough pea is mostly grown as a winter annual; it does not make much growth during the winter and therefore matures too late in spring to be followed by a spring crop. It produces seed abundantly (up to 1,000 lb. an acre). Usually the percentage of hard seeds is high, a characteristic which favours volunteering. The seed requires to be scarified and may be drilled at 20 lb. per acre. In other cases, broadcasting of 50 to 60 lb. per acre is recommended. There are about 15,000 seeds/lb.

The Cyprus vetch, *L. ochrus*,* is another similar annual, cultivated to some extent in the eastern Mediterranean region.

The grass pea or chickling vetch, *L. sativus*,* is an annual cold-season crop grown in India, Iran, the Near East, southern Europe and parts of Africa and South America. The foliage and seeds (non-toxic) are used for forage, and the seeds also for human consumption. In India and Pakistan, *L. sativus* is mostly grown as a catch

crop in rice fields during the winter. In the U. S. S. R., grass pea is recommended for green manure where sugar beets are grown under irrigation. It has been tested in the United States but is of small importance there. Many varieties exist, differing in flower and seed colour, growth of plant and size and shape of the seed. Varieties with large white seeds are superior for human food, while those with strong vegetative growth are preferred for fodder. The grass pea has 5,000 seeds/lb. and 70 to 80 lb. are sown broadcast per acre (U.S.A.); in Pakistan, the seed rate is 20 to 40 lb.

The flat pea, *L. sylvestris*,* is a perennial, rhizomatous herb, with toxic seeds in Europe and the Caucasus. It is sometimes grown for forage and has been recommended for erosion control on cutover or burned-over areas in the United States. There are 8,000 seeds/lb. and 60 to 70 lb. are sown broadcast per acre (U. S. A.).

LENS: Lentil

The common lentil (*Lens esculenta* = *Ervum lens*) is a very old crop plant grown mainly for its edible seeds used for human consumption. It has also some importance as a feed for farm animals and for soil improvement in rotations. It is 1 to 2 ft. high, an erect, bushy, annual herb of Near Eastern, Abyssinian and Indian origin. It is now widely cultivated in temperate and sub-tropical climates, and in the tropics at high elevations and as a cold season crop. It is of special importance in northern India and Pakistan where it is grown up to 11,500 ft. mostly as a pure crop but sometimes mixed with others. It may be grown dry, unirrigated or, less commonly, irrigated. In the Mediterranean countries, in Washington State, (U.S.A.), and in Chile, the lentil is also an important crop plant. It is cultivated in the central plains in Argentina as a winter annual without irrigation and only for human consumption. There are two distinct varieties: *macrosperma* and *microsperma*. In India, seeds are broadcast 30 to 80 lb. per acre and in the United States 12-15 lb. are sown per acre in rows 3 to 4 ft. apart.

LESPEDEZA

There are about 125 species of *Lespedeza* growing wild, mainly in temperate eastern Asia and Australia. About 20 species are native to the eastern United States. All but two (the annuals *L. stipulacea* and *L. striata*) are herbaceous or shrubby perennials. Only three species are of any real value in agriculture; these are the two annuals mentioned, and the perennial *L. cuneata*, all from east Asia. They are widely grown in the United States, south of the Potomac, Ohio, and Missouri rivers and east of Kansas and Oklahoma. They have

also been tested in many other countries, such as Central and South America, Japan, Africa and Australia, but so far they have acquired importance only in the United States. Even there, *Lespedeza* has been used in agriculture only for the last 50 years, but it is now estimated to cover about 50 million acres of cultivated and pasture lands. The species are especially valuable as they are better suited to soils of low fertility, even if very acid, than clovers and lucerne, and are much more drought resistant. They respond very well to phosphatic fertilizers; if this element is not available, it must be applied to give a good growth. These species are hot-weather and short-day plants and rather slow in growing in the spring. All species of *Lespedeza* have trifoliolate leaves, but the shape of the leaflets varies from linear to ovate. The lavender flowers are conspicuous in the shrubby species but inconspicuous in most of the herbaceous perennials and annuals. These species are all mostly self-fertilized. No inoculation of seed is needed in the United States.

Sericea or perennial lespedeza, *L. cuneata* (= *L. sericea*), is a herbaceous erect perennial, somewhat resembling lucerne, well adapted to poor, heavy upland soils, very durable and drought resistant. If phosphate is added, it is especially valuable for erosion control on poor, eroded clay and silt of acid reaction and low fertility. When fully developed it attains a height of 2 to 5 ft., but when cut for hay (2 to 3 times a year) it should not be more than 10 to 15 inches tall. This species is also used for pasturing and soil improvement. It is best adapted to the middle latitudes of the United States lespedeza region. It is a good seed producer and easy to establish. The seeds must be scarified before sowing. (350,000 seeds/lb.; 10 to 15 lb. or more of hulled seeds are sown broadcast per acre).

Korean lespedeza (*L. stipulacea*) and Common or Japanese lespedeza (*L. striata*) are the two species most widely grown. They are small, erect annual spreading herbs. Korean is best adapted to the northern and Common to the southern part of the lespedeza area in the United States. The first species is larger and earlier than Common, and better suited for hay making. It bears seed only in the tops of the branches and, at maturity, the surrounding leaves turn upwards to cover and protect them. Varieties of Korean lespedeza are: Harbin, Climax, early and late Korean. Rowan is a variety recently released by the North Carolina Agricultural Experiment Station, characterized by a rather high degree of resistance to root knot, nematode and powdery mildew. Varieties of Common are: Kobe and Tennessee 76, the latter characterized by large size of plant and more erect growth habit. These two annuals are sown alone or in winter grain, broadcast or drilled, and thrive with grasses which do not form a dense turf. They are used for pasture, hay, erosion control or green manure. Pasturing should not commence before June or July in the United States. Korean lespedeza has about 225,000 seeds/lb., Common 370,000; 10 to 15 lb. of Korean and 8 to 10 lb. of Common are sown, broadcast or drilled, per acre. The lespedezas reseed themselves profusely — a valuable character in a pasture and green manure plant.

Seed yields of Common lespedeza are about 150 lb. per acre, and of Korean and Sericea 200 to 250 lb. About 100 million lb. of lespedeza seed are harvested annually in the United States.

Other species are the shrubs, *L. bicolor*, *L. cyrtobotrya* and *L. cystoides*, and the herbaceous perennials, *L. formosa*, *L. hedysarioides*, *L. japonica* and *L. latissima*.

LEUCAENA

This genus comprises about 10 species of evergreen, spineless trees and shrubs, rather similar to *Acacia*. They are native to Central and South America and the Pacific Islands.

The white popinac, koa haole or lamtoro, *L. glauca*,* is a deep rooted tree or arborescent shrub, $6^1/_2$ to 33 ft. high, with bipinnate leaves, lanceolate leaflets and yellow-white flowers in long-stalked heads. It originates in tropical America, but has now become pan-tropical, especially in moist regions at low altitudes. It requires good drainage, but is adapted to relatively low soil fertility. In Ceylon, it grows freely from sea level up to about 2,500 ft. within the 65 to 100 inch rainfall zone. If not controlled, it can become a pest. It is useful as a shade and browse tree (Indonesia) and, when planted densely and pruned, as a soil cover and green manure in tea, coffee, cocoa and young rubber plantations, and as hedges. In the Philippines, it is appreciated for the production of firewood.

In the Oubangui-Chari province of French Equatorial Africa, *L. glauca* is used as a soil cover in coffee plantations, where it is considered to have the advantages of maintaining soil fertility, prohibiting erosion and giving high yields of green matter. It stands repeated pruning, reseeds itself freely, but must be prevented from choking the coffee. The stumps left after cutting impede the movements of labourers in the plantations.

L. glauca is also a fodder plant. The young foliage is very palatable, rich in protein and nutritious; in some countries the seeds and pods are used as concentrates. The fodder is, however, suitable only for ruminants (cows, sheep, goats) whereas it is toxic to monogastric animals, such as horses and pigs. The toxicity is caused by an alkaloid, mimosine, present in the leaves and seeds, which produces a disease in which the animals lose their hair. *L. glauca* is also suspected of causing sterility in cows and sows. When grown for fodder, the first cut (2 to 4 inches above ground) can be taken 6 to 9 months after sowing and the following cuts at intervals of about 4 months. It can be cultivated as an annual, biennial or

perennial crop plant; in Fiji, it is used mainly as a soil improver in a system of " long fallow " rotation.

Takahashi and Ripperton (1949), writing about Hawaiian experiences with *L. glauca*, state that:

> " Koa haole, while not outstanding as to yield, is rugged, persistent, and able to withstand weed infestation, which should appeal to dairymen of Hawaii. Once established it requires little more field care than does Napier grass. Its low moisture requirements and ability to recover after drought extends its usefulness to lands not suited to other legumes. By complete mechanization of all cultural and harvesting operations with machinery already developed, production costs should be at a minimum. Little or no fertilizer is required and infrequent irrigations suffice. Its use, however, is restricted to elevations below about 700 feet and in areas with not more than about 65 inches of annual rainfall ".

For prepared fields and planted pastures it is desirable to interplant koa haole with some sort of grass cover. The grass should be interplanted 2 to 3 months after the seeding of koa haole to permit free cultivation of inter-row spaces during the early stages of growth also to give the slower growing legume sufficient time to become well established. Guinea, Bermuda and Dallis grasses are very suitable for such interplantings.

Hawaiian beef ranchers have planted koa haole rather extensively in their pastures, generally in mixture with grasses such as Guinea grass (*Panicum maximum*). Hard and continuous grazing leads to its extermination; moderate grazing has frequently been continued for up to 6 months without damage.

R. L. Pendleton (1950) reports that in the Philippine Islands *L. glauca* is important in controlling *Imperata cylindrica*. If fire can be kept out of the grass for about 2 years after the *L. glauca* seed has been broadcast, the young plants will grow rapidly through the grass and choke it; in about 3 years there is a complete stand of leguminous shrubs.

Leucaena glauca seeds profusely in most climates where it is grown, but a variety in Indonesia does not set seed there. In mixed cultures and in rotations, it is sometimes very difficult to eradicate this plant, as it reseeds itself freely. In Indonesia, therefore, a related species, *L. pulverulenta*,* from northern Mexico and the southern United States has been tried. It does not set seed in moist climates and can be grown in dense rows and pruned in the same way as *L. glauca*. When grafted on the latter, it grows well and develops into a good shade tree. A third species, tried for the same purpose in Indonesia, is *L. glabrata** which is propagated by bud grafts. Crosses between *L. glauca* and *L. glabrata* are used also.

L. glauca is nearly always propagated by seeds and has about 12,000 per lb.; *L. glabrata* has 7,000 and *L. pulverulenta* 25,000 seeds/lb.

In Hawaii 15 to 30 lb. of seed per acre are used for forage production. The seeds are sown 2 in. deep in rows 2 1/2 to 4 ft. apart. Mature seed may contain as much as 95 per cent. hard seed. The impervious seed coating can be readily broken by hot water, chemical or mechanical scarification. In Hawaii, the method of feeding the seed mixed with molasses to animals on the range is sometimes used. In an experiment 58 per cent. of the seeds were recovered in the faeces. They had a germination capacity of 85 per cent.

LOTONONIS

Several species are indigenous in Africa. Some, e. g., *L. laxa*, are known to cause prussic acid poisoning of livestock. Attention has recently been drawn in the Transvaal to *L. bainesii*, an indigenous species from the interior of Africa near the Tropic of Capricorn. It has stems about 1 ft. long and runners with taproots at the nodes. When heavily grazed it closely resembles subterranean clover. The flowers are tiny and yellow and appear in clusters on stems 6 to 9 inches long. The pods are only half an inch long and the seeds are very small. In ripening, the bottom half of the pod opens and the seeds are shed. The plant thus reseeds itself freely, but harvesting of seed is difficult. Propagation can also be done by runners. *L. bainesii* is adapted to damp, sandy soil, but also grows well on many other types even if acid. It is fairly frost resistant, very palatable, and well suited for growing with grasses in pastures.

LOTUS: Trefoils

Only a few of the 100 species of this genus are of real value in agriculture. These are fine-stemmed, leafy perennials with sessile leaves and comparatively large flowers, yellow or red in colour; the long narrow seed pods are said to resemble a bird's foot. They are mostly adapted to a comparatively cool climate, rather acid, poor soils and wet localities, but *L. corniculatus* is also drought resistant on shallow soils. They are deep-rooted, produce fodder in late summer, and will sometimes grow where lucerne and clovers fail.

Birdsfoot trefoil (*Lotus corniculatus*) * is a native of temperate Europe and Asia, preferably used for pasture, but also for hay in that part of the world, and in North America, Australia and New Zealand. In South Africa, it is recommended for pastures. It has shown promise in mixed sown pastures in Argentina. It has a strong taproot and procumbent stems, flowers yellow or sometimes red in colour. The leaves are sessile and have 5 leaflets. Birdsfoot

trefoil is fairly hardy, thrives in water-logged areas and is better adapted to salinity and high temperatures than the more important *Trifolium* species. It is not aggressive and is easily crowded out a mixture, e. g. by red clover. Where red clover or lucerne in do not thrive for some reason, they may be replaced by birdsfoot trefoil. As the seeds shatter readily, great care must be taken at harvest. A related species with a lower chromosome number is the small *L. tenuis*, * found wild in pastures. There are few bred varieties of birdsfoot trefoil. A new North American variety, Empire, is described as a long-term hay and pasture strain, and the Danish Roskilde strain is valued in Denmark. There are 325,000 seeds per lb. and 5 to 8 lb. of seed per acre suffice when this species is sown alone; in a mixture much less is sufficient. The cyanophoric properties of birdsfoot trefoil vary widely, but are usually not a problem. It is seldom attacked by disease or insect pests.

Big trefoil (*Lotus uliginosus* = *L. major*) * resembles birdsfoot trefoil. It is larger, less winter hardy, not adapted to salinity and more moisture-loving. It is used in the same way as birdsfoot trefoil, especially on low, wet lands and in high rainfall areas in Europe, North America and New Zealand. It is well established in the wet Patagonian Andes. There are a million seeds to a pound and 3 to 5 lb. are usually sown per acre, less in a mixture.

Two other promising Mediterranean species are *L. hispidus* and *L. tetragonolobus*. Of these, *L. hispidus* is a trailing, rather drought resistant fodder plant and *L. tetragonolobus* a prostrate species grown for its edible pods. In Australia, a wild palatable species (*L. australis*) * is somewhat poisonous (hydrocyanic acid).

Seeds of the trefoils are produced in Europe, North America and New Zealand. As the seed pods ripen very unevenly and open and scatter their seed when mature, seed production is difficult and seed yields are normally comparatively low.

LUPINUS: Lupins

The lupins constitute a large genus with several hundred species. Some are indigenous to North or South America, but there is also a centre for annual species in the Mediterranean area. The agriculturally important species have all spread from the latter area, and are mostly used as cover or for soil improvement. Most lupins are herbaceous plants, but there are also many shrubs. Lupins are able to produce large amounts of herbage or seed when grown on sandy and acid soils, but when mature they are more or less poisonous to horses, cattle and especially sheep. Nevertheless, in South Africa, sheep are pastured on bitter lupins where they also collect ripe seeds on the ground. The poisonous compounds are alkaloids.

Alkaloid-free or sweet strains of *L. albus*, *L. angustifolius* and *L. luteus* have been bred, thus making these species, formerly mainly used for green manure, important fodder crops for sandy soils. Because of their thick juicy stems lupins are unsuitable for haymaking, but alkaloid-free strains are now used in mixtures with maize or other cereals for silage. By soaking in water, the alkaloids of bitter lupin can be destroyed and the treated hay or seeds used for feeding. One species (*L. termis*) was cultivated in Egypt many years B. C. and some Romans recommended lupins for green manure; they have been used for centuries throughout the Mediterranean region and more recently in large areas of Europe, Asia and Africa. Lupins have attracted the interest of farmers in the United States, especially in the south-east and cultivation is spreading rapidly. Lupins are also grown in South Africa, Australia and New Zealand.

The cultivated lupins are annual, upright, coarse herbs, which branch freely when given sufficient space. The leaves are palmate with 6 to 8 leaflets and inflorescences are large and terminal. They are deep-rooted and have thick tap roots. The young plants first develop a strong root system and very few leaves and stems. At this stage they cannot compete with aggressive weeds, but later the stems, 2 to 3 1/2 ft. high, are developed with an abundance of leaves: then the lupins can compete successfully with weeds. In cooler regions lupins are grown as summer annuals, in warmer regions as winter annuals.

Lupins usually shatter their seed profusely when ripe, a great obstacle to seed production; non-shattering varieties have recently been bred in Europe and South Africa, no doubt facilitating seed growing and reducing the price.

White lupin (*L. albus*) * is a white-flowered species, 2 to 3 ft. high, from the Levant, adapted to the warmest parts of the Mediterranean area and the Sahara. It is not much grown in North America, but is the only species cultivated in Argentina. It needs fertile, neutral soils. Blue or narrow-leaved lupin (*L. angustifolius*) * requires neutral soils of moderate fertility. It is a Mediterranean species, 2 to 3 ft. high, that has recently come to be cultivated extensively in Europe, New Zealand, Australia, South Africa, and the United States. Yellow lupin (*L. luteus*)* is another Mediterranean species, 1 to 2 ft. high, which does well on sandy, moderately acid soils of low fertility. It is an important crop in Europe and South Africa, and promising in North America.

	No. of seeds per lb.	Seeding rate (U.S.A.) lb. per acre
L. albus	1 500	100–120
L. angustifolius	2 500	50–80
L. luteus......	4 000	50–80

Other species of interest are *L. digitatus* * in North Africa, Asia Minor and Nubia; *L. hirsutus*,* an old agricultural crop of S. Europe; *L. pilosus** from the Levant, similar to *L. hirsutus; L. tassilicus** in North Africa and Asia Minor; *L. termis*, the old Egyptian lupin, similar to *L. albus* also grown in Nubia on flooded land too hard and salty for other crops; *L. caudatus*,* a North American species, rather palatable, particularly poisonous to cattle and horses, less so to sheep. Another North American species is the tall, many-leaved lupin (*L. polyphyllus*),* an erect perennial. Other dryland perennials in North America are *L. rubricaulis*,* *L. sericeus* * and *L. wyethii*. *

MEDICAGO: Lucerne or Alfalfa, Medicks

The fifty or so species of *Medicago* are all herbs or small shrubs, distributed from the Mediterranean area eastwards to Turkistan, northern India and western China. They are adapted to drought periods and to all soils which are not deficient in lime or too high in moisture. About 25 species have been tested as agricultural crops. Lucerne, common or purple alfalfa (*M. sativa* and *M. varia*) is by far the most important of the cultivated species. It is sometimes also called purple medick, snail clover, Burgundy or Chilean clover. It is a deep-rooted, perennial herb with a thick trunk root; from the root crown arise a number of erect stems carrying trifoliolate leaves and purple flowers in clusters of ten to twenty. It demands sunshine and tolerates high temperatures so long as they are not combined with high air moisture. Lucerne is generally grown alone, but also occurs in mixtures with grasses or other legumes. It is used for green fodder, for conservation as hay, silage or dried, for pasture, but does not tolerate close grazing very well. Lucerne is an excellent soil improver; it adds nitrogen to the soil, and its extensive and deep root system opens up and drains the subsoil for subsequent crops. Being so deep-rooted, lucerne is after the seedling stage little influenced by short or not too severe droughts. This is due not to its capacity to economize with water supplies, but to its ability to take up water from depths below which the water level seldom sinks. Lucerne is grown extensively under irrigation.

Lucerne was the first herbage plant to be cultivated; it was grown in Persia as early as 700 B. C. and was introduced into Greece about 500 B. C. It spread to Italy in the first century A. D., to Spain in the 8th, to France and Germany in the 16th. It was not grown in Britain until the end of the 18th century, and was taken to North America, Australia and New Zealand from Europe at about that time or earlier. Lucerne has been carried to most countries

during the past 150 years and is now grown from north-western Europe, Canada and Alaska to the desert regions adjoining the tropics in the northern hemisphere, and from the tropical highlands southward in the southern hemisphere; it is thus widely distributed throughout the areas of agricultural settlement. It cannot be grown in most parts of Egypt because, being a perennial plant, it carries some cotton pests over the dry season.

Lucerne has a very wide range of genetical variation, reflecting the extreme differences of regional and human environment under which the numerous forms have been evolved. Prior to the establishment of cultivation in most new countries, independent introductions were made from Europe or Asia by the early settlers. Seed brought from different regions was exposed to environmental selection. Although lucerne developed fully as a crop in the United States only in 1850 when seed was brought to the Pacific Coast by gold seekers from Chile, it is recorded as having been introduced into Georgia as early as 1736. It is obvious that considerable variation already existed in Europe and Asia before the material was transferred to North America from these continents. Russia and Turkestan had become noted for winter-hardy and wilt-resistant types, northern India for a drought resistant form (Ladak), and Turkey for a creeping type.

Two main species of lucerne occur in Europe and Asia; the standard form, *Medicago sativa*, and a rhizomatous frostresistant but relatively unproductive species known as sickle medick (*M. falcata*), which over-winters successfully in Alaska where most other varieties are killed. *M. falcata* occurs naturally in Siberia and the Eurasian region of comparable climate. Since it is rather difficult to harvest seed because of shattering of pods, it has not become a cultivated crop. *M. sativa* occurs nearer to the Mediterranean. Where their distributions coincide, natural hybrids occur; hybrid forms have sometimes been identified as *M. varia* (syn. *media*) and have yielded the hardy strains cultivated under the general name of variegated alfalfa or lucerne. It is probable that the creeping rhizomatous forms found growing spontaneously in North America and the southern hemisphere have been derived from such natural hybrids. Breeding to develop superior creeping strains has been undertaken in Canada, the United States, Australia and other countries. True *M. sativa* usually has purple flowers whereas *M. falcata* is characterized by yellow flowers. Hybrids and intermediate forms are frequently variegated. The hybrid forms are often similar to purple lucerne and are often incorrectly considered to belong to that species.

Other hardy species promising for breeding purposes are *M. ruthenica*, *M. platycarpa* and *M. tunetana;* the last is indigenous to the Mediterranean area and has spreading rhizomes.

There are about 220,000 seeds/lb. and 10 to 30 lb. are usually sown broadcast per acre, more in cool moist climates and less in hot,

dry climates. In Queensland, 5 to 10 lb. per acre are sown in drills or 14 lb. per acre broadcast; only 1 to 2 lb. per acre are used in mixtures with Rhodes grass (*Chloris gayana*).

In all lucerne-growing countries, many strains have developed which are especially adapted to the conditions of their respective regions of cultivation. They are usually named according to the country, state or province of origin, and much lucerne seed is put on the market under such names. In recent decades, much breeding work has been done in many countries and the results also marketed under special names. The characteristics of the more important local strains and bred varieties are briefly described below.

In the United States, it has been found convenient to divide strains, including the so-called *varia* types, into four main groups. This grouping is followed here to avoid too much repetition.

A. The Common Group

This consists of pure *sativa* types, is purple-flowered and possesses only limited winter hardiness. The American types of this group were introduced from Spain, via Chile, to California in 1850.

Hungarian, from Hungary, has a short growth period and rather good winter hardiness, and has been grown widely in central and north-western Europe. After the Second World War, the seed export of Hungary dwindled and little original Hungarian seed is now obtainable.

Italian and *Spanish* lucernes are similar to the variegated Provence (*see* over) but less winter-hardy. They are very productive in the Mediterranean climate.

Buffalo is a variety developed by the Kansas Agricultural Experiment Station. It gives high yields, recovers rapidly after cutting, and is resistant to bacterial wilt.

Williamsburg is a selection from the Williamsburg Branch Experiment Station, Virginia, very persistent and resistant to *Sclerotinia* rot in Virginia.

Talant is a French strain introduced to southern Oregon and northern California, (U.S.A.), characterized by rapid recovery after cutting and producing heavy yields of both green matter and seed. It is resistant to stem nematodes.

Argentine lucerne is grown on vast areas in Argentina; it is also grown to some extent in United States where it resembles the Common strains, but is inferior in yield and not very hardy.

South Africa is grown in the Union of South Africa, mostly under irrigation but also as a dryland crop. It is less winter hardy than the Common American strains.

Hunter River is a local strain in New South Wales, adapted to Australian conditions between latitudes 25° and 45° South.

Booborowie was developed by the Department of Agriculture, South Australia, similar to Hunter River, very drought resistant and adapted to dryland conditions.

Marlborough, a local New Zealand strain, well adapted to a temperate climate, with wide adaptability. The Department of Agriculture in New Zealand propagates selected strains.

B. The Turkestan Group

This also belongs to *M. sativa* and originates from central Asia; it is purple-flowered. The growth is shorter and more spreading than that of the Common group. Recovery after cutting is slow, winter dormancy starts early. Seed yield is low. This group is resistant to cold and bacterial wilt.

Turkestan was introduced to North America in 1898 and later, being winter hardy and adapted to the northern Great Plains, to the far West and the Middle West. Resistant to bacterial wilt.

Nemastan, introduced to Utah and Nevada, resistant to stem nematode also somewhat resistant to bacterial wilt, susceptible to leaf spot. Fair yield.

Hardistan, named by the Nebraska Agricultural Experiment Station, is a local strain of Turkestan origin which first gained prominence in Nebraska because of its persistence on wilt-infested soils. In addition to its resistance to bacterial wilt, this variety is superior to Grimm in cold endurance, is low in seed yield, and is highly susceptible to leaf spot, yellow-leaf blotch, and stem nematode.

Nomad is a pasture variety spreading by underground stolons, persistent, drought and cold-resistant, endures close grazing well, and recovers slowly after cutting. Seed production is comparatively low. Seed is certified by Oregon State College.

C. The Variegated Group

The types in this group originate from crosses between *M. sativa* and *M. falcata* and are characterized by varying flower colour (white, cream, yellow, blue, bluish green, smoky green and purple).

Provence is a local strain resembling *M. sativa* from south-eastern France with a long growth period and rapid growth, but only a low degree of winter hardiness.

Flemish, several local strains grown in northern France under names, such as Chartainvilliers, Socheville, etc. They are winter hardy, fast-growing, persistent and also good seed producers in a comparatively moist climate. Selections from Flemish lucerne include Ormelong and du Puits. Flemish lucerne has recently attracted much interest in Scandinavian countries and Great Britain.

Franconian, a local strain from Germany, winter hardy, persistent and high-yielding.

Poitou, a French natural selection of Franconian, less hardy and more adapted to a maritime climate.

Grimm, a strain of Franconian introduced to Minnesota in 1857, which has become adapted to conditions in the northern United States. It is very winter hardy and high-yielding, but susceptible to bacterial wilt. This strain is grown widely in North America and the Scandinavian countries.

Canadian Variegated (*Ontario Variegated*) is similar to Grimm but less winter hardy. Widespread in Canada, the United States and Scandinavia.

Grimm Sask. 451 and *Sask.* 666 were selected by the University of Saskatchewan, Saskatoon. They are adapted to a cool climate with moderate rainfall and are winter hardy and drought resistant. No. 666 is more uniform.

Canauto is a selection by the Central Experimental Farm, Ottawa, from Grimm Sask. 666. The flower colour is not variegated. It is adapted to severe winters and moderate rainfall and has a good seed yield. This variety has a high percentage of plants which produce self-tripping flowers.

Viking, from the Dominion Forage Crop Laboratory, Saskatoon, is very winter-hardy, high-yielding in the first cut, resembles Ladak, to which it is superior.

Ferax, from the University of Alberta, is winter hardy and sets seed well.

Baltic, a local strain from South Dakota of European origin, hardy and similar to Grimm.

Hardigan, a selection from Baltic made by the Michigan Agricultural College, shows very little variegation and produces heavy seed yields during occasional hot summers in regions normally quite humid.

Cossack was introduced from Russia to the United States in 1907, and tends to yield better than Grimm, which it resembles.

Ladak was introduced from India to the United States in 1910. It is highly variable, very winter hardy and produces a heavy first cut. Recovery is slow and winter dormancy comes early. It is moderately resistant to bacterial wilt and is drought resistant.

Ranger, a synthetic variety involving strains tracing to Cossack, Turkistan and Ladak, was produced by the Nebraska Agricultural Experiment Station and the United States Department of Agriculture, is variable and recovers rapidly after cutting. It is slightly susceptible to leaf spot and leaf-hoppers, but is resistant to bacterial wilt. It is as winter hardy as Grimm and a good seed producer.

Atlantic, from the New Jersey Agricultural Experiment Station, high-yielding and adapted to the eastern states of the United States, is not resistant to bacterial wilt and is rather short-lived.

Narragansett, from Rhode Island Agricultural Experiment Station, is high-yielding and long-lived, but not resistant to bacterial wilt.

D. The Non-Hardy Group

These strains have an erect growth habit, good recovery after cutting and a long growing period. They are adapted to short days and susceptible to low temperatures and bacterial wilt.

Peruvian (smooth and hairy) are strains introduced from Peru to the United States in 1899. They show rapid growth, quick recovery after cutting and have a long vegetation period. In the United States they are grown only in the extreme south-west, mostly under irrigation. This strain is common in the countries of the eastern Mediterranean.

Indian was introduced from Poona, Bombay State, to the United States in 1913. It has the same adaptation as Peruvian, but a somewhat better yield.

Egyptian, introduced to the United States from Egypt in 1927, has the same adaptation as Peruvian and Indian.

There are certain Argentine local types, e. g., *Rio Negro*, *Saladina*, *San Rafael*, *Villerino*, *Pampeana* and *Cordoba*. A new selection, *Alfalfa Faculdad San Martín*, has been made by the Faculty of Agronomy, Buenos Aires, which is resistant to stem nematodes and very persistent. A strain of this group bred in Kenya is called 37S.4.

Breeders have given much attention to the development of varieties better adapted to pasture conditions. These may be types with a spreading growth habit with branches rooting at the nodes, or truly rhizome-producing types. Such forms are found among the *media* strains, and it is possible that true breeding strains with these characteristics may be developed in the near future.

Black medick (*Medicago lupulina*), other species also called yellow trefoil, black seed, nonesuch, hop medick and hop clover, is an annual or biennial semi-erect herb adapted to a wide variety of soils with a good supply of lime in temperate moist climates. It is not very high in yield or drought resistant but re-seeds itself and volunteers in pastures and meadows. Seed is produced in Europe, Argentina and Australia. There are about 300,000 seeds/lb. and normally 10 to 15 lb. are sown broadcast per acre.

Bur clovers include several annual species of *Medicago*, all indigenous to the Mediterranean area, with weak stems, trifoliolate leaves and inconspicuous yellow flowers. They are either grown intentionally or volunteer in pastures, and they thrive in climates with mild winters and more or less extended summer droughts. They re-seed themselves or are sown in the autumn. Species include: *Medicago arabica* (*M. maculata*), spotted bur clover or spotted medick, also called southern bur clover, heart clover or heart trefoil, purple grass or St. Mawes clover; *M. hispida* (*M. denticulata*) bur clover or Californian bur clover, toothed medick or toothed bur clover; *M. minima*, little bur clover; *M. orbicularis*, snail medick or button clover; *M. rigidula*, tifton bur clover; *M. scutellata*, snail medick and *M. truncatula* (*M. tribuloides*), barrel medick.

Most of these species are of some importance in pastures in those parts of the world where a climate of Mediterranean type prevails. During the dry season the abundant dry fruits constitute a valuable concentrated fodder for pasture animals. *M. hispida* and *M. minima* are undesirable for sheep pastures as the fruits or burs become entangled in the wool of the sheep. *M. truncatula* is very popular

as a pasture plant in Australia because the spines of the fruiting pods are not hooked. A local strain propagated by the Waite Agricultural Research Institute in Adelaide, South Australia, is vigorous, prostrate and adapted to mixed pastures and alkaline soils. The climatic adaptation is similar to that of subterranean clover. Bur clovers have usually 150,000 to 200,000 seeds/lb., but *M. minima* has 400,000 and *M. scutellata* only 45,000 seeds. Seeding rates in the United States are about 20 lb. of hulled seeds and up to 100 lb. of unhulled seeds per arre. In Australia, only 1 to 2 lb. per acre are used. Seeds are produced in the southern United States and Australia.

MELILOTUS: Sweet Clovers

This genus comprises about 20 species which seem to have originated in Asia Minor and are now widespread in the temperate zones. The species *M. indica* has long been cultivated for forage in India and, together with *M. alba*, *M. officinalis* and *M. suaveolens*, has attracted much interest in other countries; they are now widely grown, especially in North America. The sweet clovers are biennials or annuals with a growth habit somewhat similar to lucerne. The leaflets are narrow and the flowers yellow or white. They are adapted to temperate climates and to neutral or alkaline soils with a fair amount of available lime, and are very tolerant of summer drought. Sweet clovers have a characteristic smell of coumarin, a substance found in all parts of the plant. If the hay or silage is poorly harvested or fermented, a decomposition product of coumarin is formed which is toxic to animals, causing external and internal bleeding. There are about 250,000 to 275,000 seeds/lb. and 10 to 15 lb. of seed are normally sown per acre, broadcast or in close drills.

Sweet clover (*M. alba* and *M. officinalis*) has become a most important cultivated legume of western Canada since its introduction 40 years ago. This crop is apparently adapted to a wide range of soil and climatic conditions and has also been extensively grown in the northern United States. The widespread Arctic variety of *M. alba* was developed directly from seeds originating in northern Siberia. Considerable work has been carried out in Canada and the United States to produce improved forms of these species by breeding.

Melilotus alba,* white sweet clover, Bokhara sweet clover, honey clover or white melilot, is a biennial, but annual types also occur (e. g. the variety Hubam). It is grown for pasture, hay and soil improvement in North America and the southern temperate zone. Depending upon the climate, it is sown either in the spring or in the autumn.

Melilotus indica (with the sub-species *parviflora*),* yellow annual sweet clover, sour clover, Indian clover, King Island clover or senji, is an annual indigenous to the Punjab, grown in India as an irrigated cold season crop, and in the southern states of the United States. In Argentina, Tasmania and South Australia it is sometimes considered a pest in wheat fields since it taints the flour. It is smaller and more bitter in taste than the annual form of *M. alba* and more adapted to hot climates than the other cultivated species. *M. indica* is also resistant to soil alkalinity and so is valuable for the reclamation of saline areas.

*Melilotus officinalis,** biennial yellow sweet clover or yellow melilot, is generally a biennial, but annual types also occur. It is more hardy and earlier than *M. indica* and *M. alba* and persists under close grazing. It is grown in the same regions as *M. alba*, but it becomes established better in dry seasons and in dry seed beds than that species. In the second year, it dies off early just when pasture is most needed.

*Melilotus suaveolens,** Daghestan sweet clover, is a biennial with annual mutations of more restricted use. In the United States it is grown only in the north central states.

As the interest in sweet clover has been specially keen in North America, most improved strains and bred varieties have originated there.

Melilotus alba: American Strains

Biennial

Common white gives high yields of hay and pasture. In the second year it reaches a height of 7 ft. Maturity medium-late.

Grundy County is a strain from Illinois, with rather short growth, early maturity, good seed yield, but poor root production.

Spanish, introduced from Spain in 1910, is leafy, upright and medium in height and maturity. Seed production good and early. Recommended for pasture and hay, particularly in irrigated regions.

Evergreen, from Ohio Agricultural Experiment Station, is tall, upright and coarse, and late in the second year. Recommended for pasture and hay, particularly in irrigated areas.

Willamette, from Oregon Agricultural Experiment Station, similar to Common white but resistant to *Sclerotinia trifoliorum*.

Annual

Hubam, from Iowa Agricultural Experiment Station, especially popular in Texas, New Mexico and Arizona, as a winter annual for soil improvement. It is also sown in the autumn or late winter for pasture in spring and early summer.

Emerald, a cross Hubam × wild plant from South Dakota, made at Lincoln, Nebraska, further selected at Texas Agricultural Experiment Station. It is shorter and less coarse than Hubam. Recommended for pasture and forage, particularly in irrigated regions.

Floranna, a selection from the Florida Experiment Station, is tolerant to poor soil conditions and volunteers well.

Melilotus alba: Canadian Strains

Biennial

Maccor, selected at Manitoba Agricultural College, has quick growth in spring, is hardy and adapted to northern areas.

Alpha, Sask. 1525, from the University of Saskatchewan. Dwarf plant, stems short, fine and leafy, flowers green. Persistent and adapted to temperate regions between latitudes 44° and 54° N. with at least 15 to 20 inches rainfall.

Arctic, Sask. 439, from the University of Saskatchewan. Erect, persistent and adapted to a cool, temperate climate between latitudes 44° and 54° N. with at least 14 to 30 inches of rainfall.

Brandon Dwarf, from Dominion Experimental Farm, Brandon, Manitoba. Dwarf growth, stems short, fine and leafy. Not drought resistant, needs at least 16 inches of rainfall.

Annual

Melana, from the Dominion Forage Crops Laboratory, Saskatoon. Growth very fine, of intermediate height, seed yield low. Adapted to conditions varying from semi-arid to humid with a frost-free period of at least 120 days.

Melilotus officinalis: American Strains

Biennial

Common yellow, smaller (3 to 5 ft.) less upright, and earlier than Common white. Drought resistant, not recommended for second year pasture.

Madrid, introduced from Spain in 1910. Good seedling vigour, medium height, foliage resistant to autumn frosts. Fine, leafy stems. Early, with good early seed production. Recommended for pasture and hay in dry areas.

Melilotus officinalis: Canadian Strains

Biennial

Aura, more erect and later than common yellow, very winter-hardy, and adapted to northern areas.

Erector, from the Dominion Experimental Farm, Brandon, Manitoba, erect, winter-hardy, wide adaptation.

Melilotus suaveolens

Biennial Strains

Redfield, introduced into United States from Manchuria, upright, late and leafy and with a compact growth habit, not adapted to the south and east of the United States.

Zouave, Sask. 788, from the University of Saskatchewan, has slender stems and is adapted to a cool, temperate climate. Moderate drought resistance.

MIMOSA

Mimosa is a large tropical genus of about 300 species of trees, shrubs and herbs, most of them indigenous to tropical America. Few are of any great importance in agriculture.

M. invisa is a vigorous, winding annual-perennial plant used for green manure and as a cover plant in Indonesia, Indo-China and some other countries. It is propagated by seeds and re-seeds itself

freely. There are about 75,000 seeds/lb.; 6 to 8 lb. are sown in rows 5 ft. apart. The very spiny stem is a drawback; for this reason it is considered a noxious weed in Fiji, the Philippines, Brazil and Paraguay. A planter in Indonesia has selected a thornless strain which may make *M. invisa* more popular. It is one of the best plants for suppressing the noxious grass *Imperata cylindrica*.

M. pudica or " sensitive plant " is a prostrate to ascending bush, native to tropical America. Together with species of *Desmodium*, this plant is said to replace, in Fiji, the clovers and trefoils of pastures of temperate climates. It also has some importance in pastures in Hawaii and Indo-China, but is not considered especially desirable there; in Queensland, it is considered a weed. It has been tested in several other countries and is considered very promising in Sierra Leone.

There are more than 60 species in Argentina and Paraguay; although many may be eaten by cattle, they are of no practical importance. Some creeping, spineless pasture species (*M. paupera*, *M. strigillosa*) may be useful; bushy species such as *M. uliginosa* and *M. somnians* are browsed notwithstanding their spines.

ONOBRYCHIS: Sainfoin or Esparcette

This genus comprises some 80 to 100 species of perennial, herbaceous or sometimes shrubby and spiny plants, native to southern Europe, northern Africa and western Asia. *O. viciifolia* (= *O. sativa* = *O. vulgaris*) is the most important agricultural species.

Sainfoin originates in central and southern Europe and temperate Asia. It is a long-lived, perennial herb with a long, thick taproot, pinnate leaves and red flowers in long terminal racemes. It is specially adapted to dry calcareous soils and is used in Central Europe, Great Britain and the Mediterranean countries as a hay and pasture plant. It has shown promise as a pasture and hay legume in dry locations of South Africa, South America and the United States. There are two distinct types of sainfoin: Common and Giant. According to J. R. Thompson:

> " Giant is to Common sainfoin as early to late red clover in respect to more luxuriant growth and more profuse flowering in the seeding year, lighter hay and pasture yields in the first harvest year, more leafy hay cut but less leafy aftermath and pasture cuts, shorter life, fewer tillers, longer flowering period, fewer flowers per inflorescence and larger leaf. In relative length of stem and number and length of internodes, however, Giant corresponds to late and Common to early red clover ".

The resistance of sainfoin to grazing is at least as good as that of lucerne and probably better. Common sainfoin withstands repeated grazing better than Giant.

Sainfoin has about 25,000 to 30,000 seeds/lb.; in the United States, 30 to 35 lb. are sown broadcast to the acre.

ORNITHOPUS: Serradella

Serradella (*O. sativus*) is a small, semi-viny, annual herb, somewhat similar in growth habit to vetches. It is a native of the Atlantic-Mediterranean regions of Spain and Morocco, but does not occur in the interior of Spain. It is adapted to moist, sandy soils of slightly acid reaction and a cool growing season. In such an environment, it is grown for forage and green manure mainly in southern and central Europe, in the south as a winter annual and in the north as a summer annual. It has been tested in many other countries, but usually with little success. From Kenya, however, it is reported that it might be of value as a catch crop giving high returns in protein and minerals in the autumn and good soil protection in the winter. Serradella is propagated by seeds, of which there are about 160,000 (unhulled)/lb. Seed rates are in some cases given as 15 to 20 lb. per acre, in others as 40 to 60 lb. per acre depending upon environment.

OTOPTERA

In the northern Transvaal, attention has recently been called to a plant (*Otoptera burchellii*) which seems to have great prospects as a binder of drifting sands. Usually this species has hard, woody stems and hard unpalatable leaves. On banked-up drifts, however, it becomes vigorous and produces a dense, hedgelike growth, also acting as a windbreak. It thus builds up sandbanks which become stabilized and eventually covered with dense grass. When once grass has taken over, the *Otoptera* reverts to its former insignificant role. All kinds of stock, as well as insects, are very fond of its pods and it is sometimes difficult to collect seeds.

PAROCHETUS

Parochetus communis is a low, creeping and quick-growing plant found at high elevations throughout Asia. It is considered a promising pasture and ground cover for high country. Recently, its value as a legume in the pastures of the high, central highlands of Ceylon was recognised. It is palatable and grows well with *Paspalum* spp. and Kikuyu grass (*Pennisetum clandestinum*) as well as with *Cymbopogon confertifolius* and *Themeda tremula;* it is probably unsuitable in mixtures with tall fodder grasses such as Napier (*Pennisetum purpureum*).

PHASEOLUS

Phaseolus is a large genus of about 200 species, mostly annual or perennial, erect or twining herbs, natives of China, India, Central and South America. They are mostly limited to warm and tropical countries, but there are exceptions. Most species are cultivated for their edible seeds and pods, but many are also important as fodder, green manure and cover crops.

Ph. aconitifolius (= *Ph. trilobus*), moth or mat bean, or phillipesara, is a herbaceous, creeping annual native to India and Pakistan. It is grown as a drought resistant, hot season plant in Ceylon, India, Pakistan, China, Texas and California, yielding palatable and nutritious pasturage and hay; in the Orient the seeds are also used. In Madras, it is considered to be the most suitable green manure to precede cotton in the rotation. It has also been tested as a green manure and cover in Indonesia, but is of little importance. In the Sudan it has shown promise, giving complete cover, but a comparatively small bulk of forage. It keeps alive with little moisture, but is not damaged by excessive irrigation; it is useful in mixtures with lablab, pigeon pea and Sudan grass. There are about 20,000 seeds/lb. and 35 to 40 lb. are sown broadcast or 5 to 6 lb. planted 30 × 3 inches apart per acre (U. S. A.); 15 to 20 lb. per acre are broadcast in Pakistan.

Ph. acutifolius, Tepary or Texas bean, is a slender annual, bushy on poor land but otherwise twining. It is a native of Mexico and Arizona and adapted to hot, dry climates, but occurs also in the humid, tropical zone of Mexico. It is a quick-growing food plant. The variety *latifolius* is the one commonly grown. There are 25,000 seeds/lb. and 25 to 30 lb. are sown broadcast per acre. This bean is not grown much outside its homeland.

Ph. angularis, Adzuki bean, is a bushy, erect annual of Chinese origin, with the same adaptation as the soyabean, grown mainly for human food but also for herbage in China, Japan, Argentina, Paraguay and the southern United States. There are 4,000 seeds/lb.; in the United States, 20 to 25 lb. are sown per acre in rows 18 inches to 3 ft. apart.

Ph. aureus, mung bean or golden gram, is a tall, slightly climbing, drought resistant annual from Central Asia and India. In India, it is mostly grown for human food but the straw may be used as fodder. In the Philippines, it is also used for green manure. Outside Asia, mung bean is grown in Central and South Africa and in South America for green manure, forage and human food (dry beans and sprouts). In the West Indies it is a short-term forage and cover crop. It is grown in the United States as far north as Michigan, but is of little importance apart from hay and chicken pasture. Mung bean is susceptible to both root nematodes and root rot (*Sclero-*

tium rolfsii). There are about 10,000 seeds/lb. and 60 to 70 lb. are sown broadcast per acre (U. S. A.).

Ph. calcaratus, red bean or rice bean, is a shortlived, very hairy, twining weed of Indian origin, used principally for human consumption. It must be cooked before eating. It is recommended as a green manure and cover crop in many warmer countries such as Indonesia, Burma, Uganda, Paraguay and the southern United States. In lower Burma, it is grown in sequence with rice as a seed crop. In the United States, its use is restricted by its susceptibility to root knot nematodes. There are about 10,000 seeds/lb. and 70 to 80 lb. are sown broadcast per acre.

Ph. lathyroides, Phasemy bean, is an erect, slightly branching annual-perennial 4 to 5 ft. high with large dark red flowers which is widespread in the coastal areas of southern Queensland. It is a summer legume but retains its leaves until heavily frosted; it shoots again from the base with the advent of spring rains and higher temperatures. In pastures it combines well with *Paspalum scrobiculatum* and similar grasses, but is also cut for hay or fed green to pigs. It is palatable and highly nutritive. It volunteers well as seeds are dropped readily. This bean has been successful in the Sudan and Southern Rhodesia. It responds well to a higher level of fertilization.

There are two distinct groups of lima beans, *Ph. lunatus*, * *microspermus* (small-seeded), according to N. I. Vavilov, originating in the South Mexican and Central American centre of origin, and *macrospermus* (large-seeded) from South America. The lima beans are perennials which are often grown as annuals. They are twining herbs, but bushy varieties also exist. They are adapted to warm humid climates and are grown under these conditions mainly for human consumption in many parts of the world. Most lima beans contain hydrocyanic acid compounds and must, therefore, be boiled or roasted before being eaten; they are also used for cover and green manure in many countries. The seeds are very variable in size. According to J. J. Ochse, in Indonesia, 2 to 3 seeds are planted together in "hills," 1 to $1^1/_2 \times 1^1/_2$ to $2^2/_3$ ft. apart.

The urd or black gram, *Ph. mungo*, is an erect, spreading annual of Indian and central Asian origin. In most tropical and sub-tropical countries, it is grown for human food and to some extent for hay and green manure. In lower Burma, it is grown in a sequence with rice as a seed crop. In India, urd is grown as a dry crop in regions with less than 35 inches rainfall; being fast-growing it is used both as an early, mid-season or late crop, but is seldom the sole crop of the year. In Indonesia, it is used for green manure and soil cover. Urd is also grown in tropical Africa and the West Indies as a short-term forage and cover crop. Seed rate (Pakistan) 10 to 20 lb. per acre.

Green gram or green mung, *Ph. radiatus*, is related to *Ph. mungo*. It is likewise an erect, short-living herb, 1 to $1\,^1/_2$ ft. high, used for

the same purposes. It is grown as a pulse throughout India, and is rapid in growth and early-ripening. In Burma, it is grown in the same way as urd in a sequence with rice as a green manure. In Ceylon, green gram has shown some promise as soil cover in new clearings for rubber. Seed rate (Pakistan) 10 to 15 lb. per acre.

Ph. semi-erectus, is a tall, erect and fast-growing herb 4 to 5 ft. high, used in Indo-China and Indonesia for green manure and soil cover; experiments indicate that it is drought resistant and well adapted as a green manure, but it is also excellent forage. In Southern Rhodesia, it stands heavy grazing well and seems to be a good hay plant.

Other species include the common scarlet runner bean (*Ph. multiflorus*) and the garden or kidney bean (*Ph. vulgaris*). They are grown in many countries for their edible beans and pods, but are of little importance for fodder or soil improvement. Both species are well-known garden crops which have many varieties adapted to special environments and to different uses. Further species include the South American *Ph. caracalla; Ph. helvolus* and *Ph. inamoenus* grown in Madagascar; *Ph. metcalfei* from the southern United States and Mexico, and *Ph. sphaericus* var. *sulphureus*, an ancient Chinese pulse.

PISUM: Peas

Within this genus there are many morphologically divergent wild types, all found in the Old World and in many cases described as separate species. Recent cytological and genetical investigations have shown however, that most are closely related, and that all wild and cultivated types have the same chromosome number ($2n = 14$). There is, therefore, no need for a number of specific names. All cultivated types are now included in the species *P. sativum sens. ampl.* and the wild forms are divided into five other species.

From a practical standpoint *P. sativum*, according to H. Lamprecht, can be divided into the following groups:

I. *P. saccharatum* with no or only a very thin lining membrane in the pod walls

   A. Types with thin pod walls

      1. Types with smooth seeds
      2. Types with wrinkled seeds

   B. Types with thick pod walls

      1. Types with smooth seeds
      2. Types with wrinkled seeds.

II· *P. pachylobum* with a well-developed lining membrane in the pod walls

A. Types with thin pod walls
   1. Types with smooth seeds
   2. Types with wrinkled seeds

B. Types with thick pod walls
   1. Types with smooth seeds
   2. Types with wrinkled seeds

The whole *saccharatum*-group and the A2 group of *pachylobum* are spoken of as garden peas, whereas groups II A1 and II B1 and 2 are called field peas. Most of the cultivated field peas belong to group II A1.

Peas may also be divided into several groups according to their use. They may be grown for:

(*a*) forage, soil cover and green manure;
(*b*) dry, edible seeds;
(*c*) green shelling peas;
(*d*) canning peas, and
(*e*) edible pods, which have no lining membrane in the pod.

Only the first two groups are usually referred to as field peas, and they are the only groups which will be considered here.

The stems of field peas are viny and the leaves pinnatifid with 2 to 3 pairs of broad, ovate leaflets, two big, leaf-like stipules and usually a terminal tendril. The flowers are large, butterfly-like, white, pink or purple, the pods inflated and the seeds mostly smooth and round, and yellow, green or dark in colour. The seed size is variable and so also is the seeding rate (from 75 to 200 lb. per acre).

This species is native to the eastern Mediterranean region, has been cultivated since ancient times and is now grown in all temperate countries. It is adapted to cool weather and does not thrive in hot and dry regions. In cooler climates, where it is often grown mixed with cereals, it is cultivated as a summer annual, and the ripe, dried seeds are used as concentrates for farm animals or for human consumption; the vines produce hay, silage and green fodder. In warmer climates, the plant is grown as a winter annual and is often used also for soil cover and green manure. Peas are sometimes grown as winter crops in sub-tropical climates with cool winters where spring temperatures are not too high. The plant needs fairly abundant moisture and neutral or alkaline soil reaction but otherwise is not very particular as to the type of soil.

In South Australia, pea crops are used for fattening lambs by direct grazing in early summer when the crop has completed growth and dried off. There is circumstantial evidence of the benefits accruing to the subsequent cereal crop, generally wheat.

PLATE 43. Tetraploid red clover in flower, Svalöf, Sweden.

Photo by courtesy of Sveriges Utsädesföreningen

PLATE 44. Photograph taken 1 July 1910 at Newell, South Dakota, U.S.A., of a hybrid between *Medicago sativa* x *M. falcata*.

(Photos by courtesy of Dr. O. S. Aamodt)

PLATE 45. Photograph taken 19 August 1916 at Newell, South Dakota, U.S.A., of a plant of alfalfa (lucerne) with proliferating rootstalks extending 4 ft. from the centre the plant.

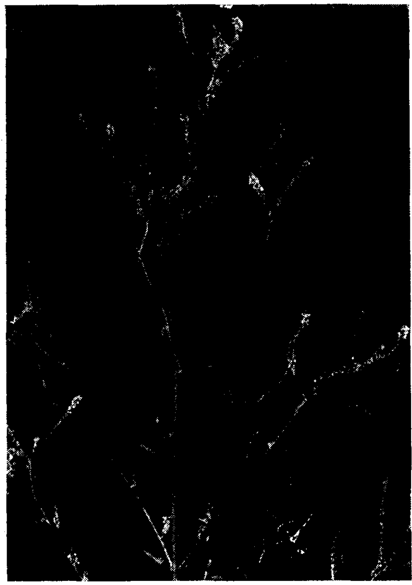


PLATE 46. Sweet clover (*Melilotus alba*) PLATE 47. Yellow-flowered sweet clover (*Melilotus officinalis*)

(Both photos by courtesy of the Division of Forage Crops and Diseases, U.S.D.A).

PLATE 48. Tropical kudzu (*Pueraria phaseoloides*) in Puerto Rico. (Photo by H. E. Warmke)

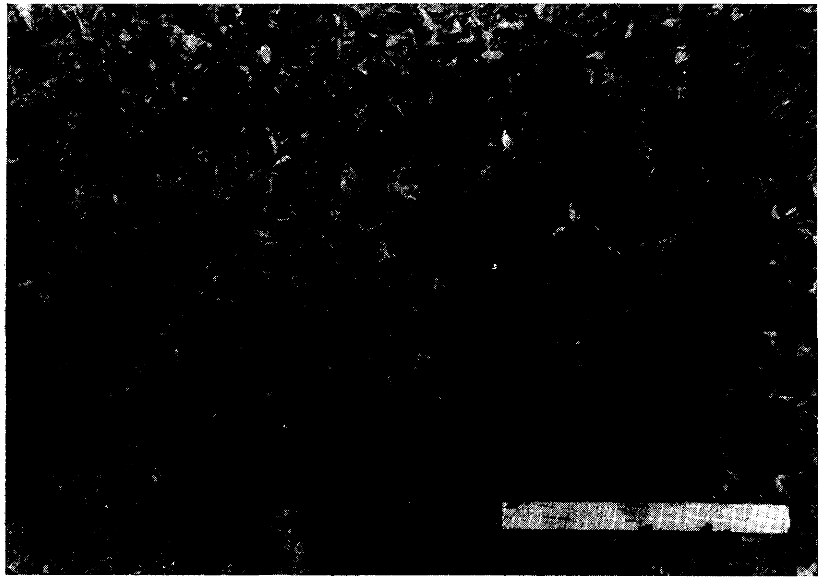


PLATE 49. *Centrosema pubescens* in Southern Rhodesia (foot rule shows the scale).

PLATE 50. *Teramnus uncinatus* in Southern Rhodesia (foot rule shows the scale).
(Photos by E. D. Bumpus)

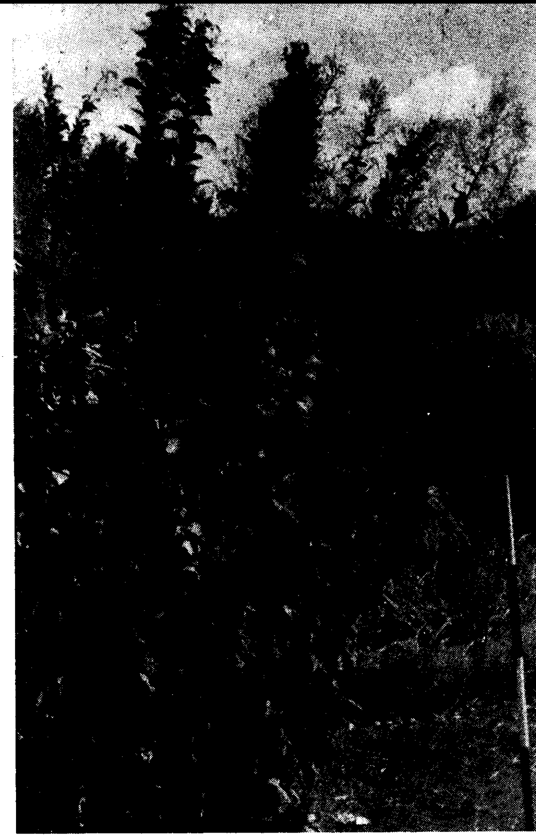
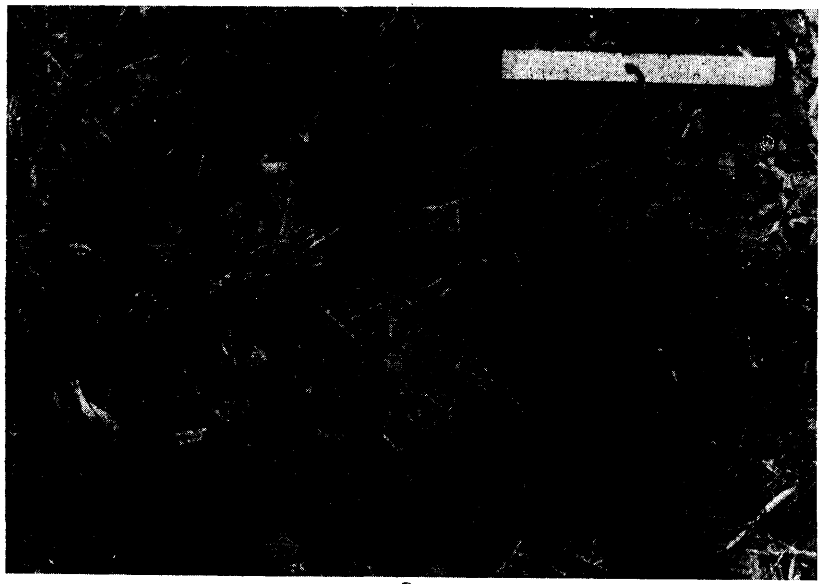


PLATE 51. *Desmodium discolor* in Southern Rhodesia (foot divisions on ranging rod show the scale).
(Photo by E. D. Bumpus)

PLATE 52. Cowpeas (*Vigna sinensis*) growing between rows of Napier grass (*Pennisetum purpureum*) at Rietvlei, Southern Rhodesia.
(Photo by courtesy of the Department of Agriculture, Southern Rhodesia)



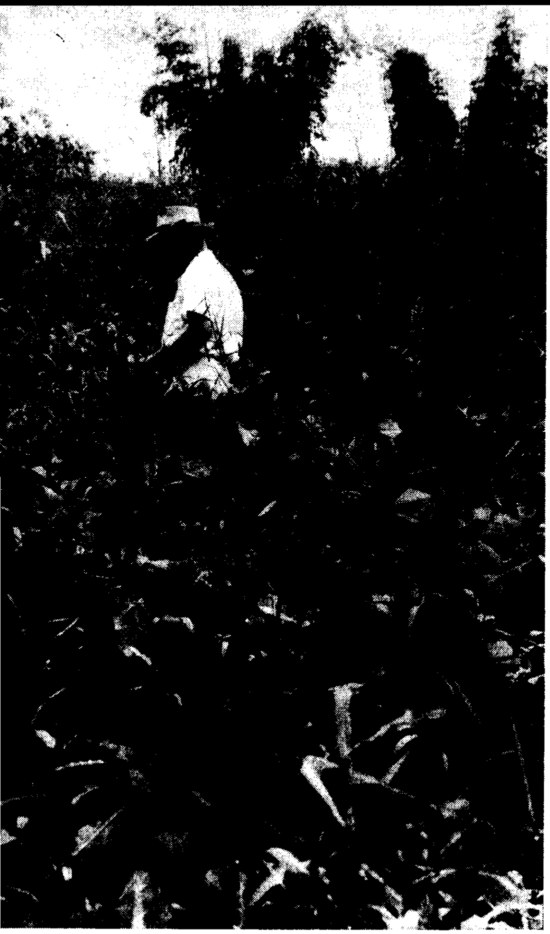


PLATE 53. Association of tropical kudzu (*Pueraria phaseoloides*) and Pará grass (*Brachiaria mutica*) in Puerto Rico.

(Photo by H. E. Warmke)

LATE 54. Association of tropical kudzu (*Pueraria phaseoloides*) and Merker grass (*Pennisetum merkeri*) in Puerto Rico.

(Photo by H. E. Warmke)

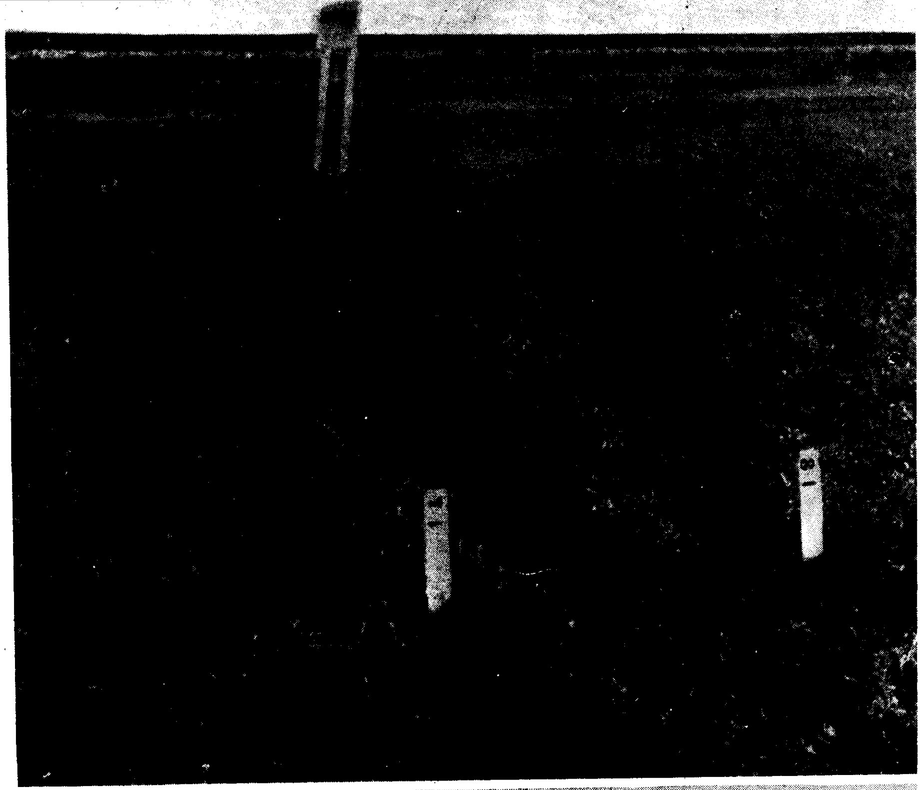


PLATE 55. Adjacent lucerne plots cut at the same date showing varietal differences in rate of regrowth, Svalöf, Sweden.

(Photo by courtesy of Sveriges Utsädesföreningen)

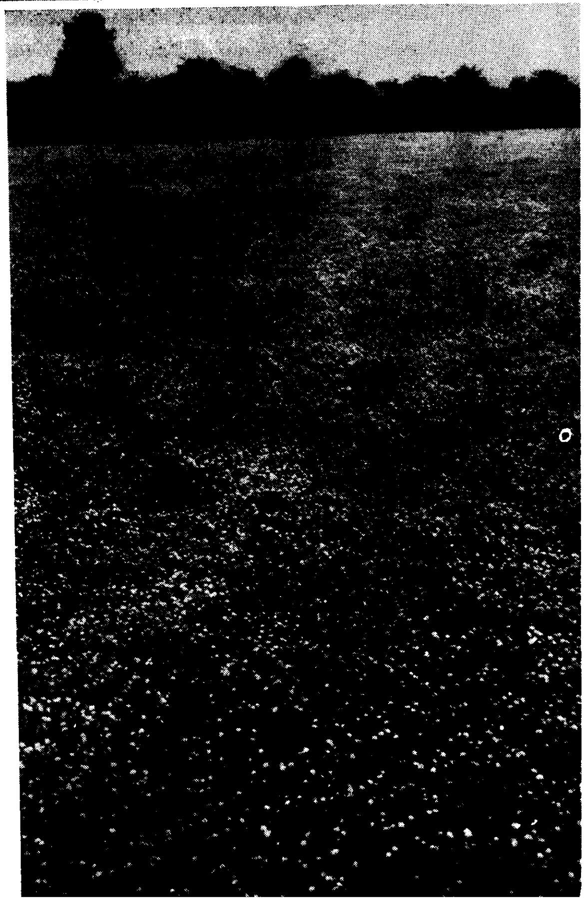


PLATE 56. Field of Persian clover in Louisiana, which had been grazed through the preceding winter, and stock removed 6 weeks before photograph was taken.

(Photo by courtesy of the Division of Forage Crops and Diseases, U.S.D.A.)

PLATE 57. A volunteer stand of Dixie crimson clover (*Trifolium incarnatum*) in the Southern U. S. A. Stock had grazed all winter at the rate of one head per acre, and were removed April 22. Photograph taken 12 May 1944.

PLATE 58. Hogs on pasture of crimson clover (*Trifolium incarnatum*) in the southern United States. (Photos by courtesy of the Division of Forage Crops and Diseases, U. S. D. A.)

The development of pea varieties, which extends back to the earliest times, has been largely the work of gardeners and commercial growers while the field husbandman has merely grown the varieties which appeared to be best suited to his conditions. There has been considerable extension in the use of named varieties of field peas in comparatively recent times; many experiment stations have made selections from the more promising varieties for introduction into commerce. The number of varietal names, mostly synonyms, is immense. No attempt will, therefore, be made here to enumerate or describe more than a few of the varieties grown in different parts of the world.

The standard variety of field pea in central Europe is Victoria, of which many different strains exist. It has long vines and large, yellow seeds. Another European type more adapted to green fodder production is Peluschken, a very long-vined, late and small-seeded variety. In the U.S.S.R., where the field pea is a very important crop, and in the British Isles and north European countries many large-and small-seeded varieties have been bred. Generally speaking, most pea growing countries have produced pure-bred varieties or local strains adapted to local conditions and to special purposes of cultivation. For warmer climates, the most popular variety is the Austrian Winter Pea, seeds of which are now produced in south-central Europe, Oregon, Washington and Idaho in the United States and in New Zealand. Among varieties grown in North America might be mentioned Alaska, Blue Bell or Blue Prussian, First and Best, Extra Early, White Canada, Early Blue, Chancellor, Arthur, Austrian Winter and Dixie Wonder.

PITHECELLOBIUM: (=Pithecolobium)

There are about 125 species of trees and shrubs of this genus in tropical regions, mainly America and Asia, but also in Africa and Australia. A few have slight agricultural value, as the leaves and pods are used for fodder, and the plants are used for hedges or as shade trees.

P. dulce, a rapidly growing tree up to 50 ft. high is cultivated in many tropical countries. It was introduced into the Sudan as a hedge plant. The foliage is particularly palatable to goats, and the clippings are carefully collected for feeding to animals. In Hawaii, it grows in pastures at lower elevations and is browsed, but it sometimes becomes a pest. In Mauritius, this tree grows well even on poor soils and is resistant to drought. The pods are very palatable. A similar Indonesian species is *P. lobatum.*

P. saman (= *Samanea saman*),* rain tree, is a native in Central and South America, but now introduced in most tropical and subtropical countries. It thrives on dry, barren soils and is used in

many countries as a shade tree, even if it is a little slow-growing. The pods have a sweet pulp relished by cattle; the foliage is also valuable fodder. In Fiji, some cases of suspected poisoning have been reported. The pods are sometimes used for manufacturing alcohol.

PROSOPIS: Mesquites

The mesquites are trees or shrubs which are very drought resistant and well-adapted to light soils and arid regions of warmer climates. In such localities they grow well with grasses and constitute a valuable emergency fodder. The young foliage, as well as the pods and beans, are relished by all farm animals without causing much damage to the trees. These trees are, however, aggressive and may easily become pests, especially when pastures are overstocked and the grass cover depleted. In such cases, control must be undertaken to permit restoration of the grass cover. In the United States, sodium arsenite is a suitable chemical for root poisoning by the trench or basin method, or for stem poisoning by girdling or frilling. Spraying from aeroplanes with 2, 4, 5-T-ester, and poisoning with kerosene poured on the ground at the base of the trees have also been very successful.

The nomenclature of the *Prosopis* species seems to be confused, and it is often difficult to be certain which species is being discussed. In the following paragraphs, the species names adopted by the respective authors have been used without any attempt at uniformity.

The algaroba, *P. chilensis*, is a tree from Chile, Argentina and Peru which is browsed in the south-western United States and the West Indies, but which is not recommended for planting because it easily becomes a pest. On dry coastal lowlands in Hawaii, it is a valuable, introduced tree providing both shade and fodder. The dropping seeds are good feed for farm animals and are also used as concentrates. This tree is also popular in Indonesia and South Africa. E. E. M. Loock reports that *P. pubescens* and some sub-species of *P. juliflora* have small valueless pods, whereas *P. juliflora* and *P. chilensis* are among the most important fodder trees imported to South Africa. They are there usually planted in poor soil and, therefore, attain a height of only 30 ft. The initial growth is slow as the plant first develops a large root system. Ripe pods have a high feeding value and are relished by all farm animals; they have the same value as maize; green pods are bitter and valueless. Pods drop and have to be gathered and stored dry. This is done on a large scale in the desert regions of Peru, where the pods are collected for the preparation of concentrates. The seeds are hard and must be crushed; leaves and shoots may also be eaten. The wood is hard and valuable. These species do well in warm, dry and protected areas and are fairly resistant to frost and cold when once established. They are drought resistant.

These mesquites are propagated by seed which must be scarified in hot water. A 10-year old tree may yield up to 200 lb. of pods per year.

In the United States (U.S.D.A., 1931), there are three related species of mesquite; the honey mesquite, *P. glandulosa* and the velvet mesquite, *P. velutina*, both from Mexico; and *P. juliflora* from Jamaica. They are all browse plants which easily become pests.

The honey mesquite, is a shrub, 5 to 10 ft. high, or a small tree, 15 to 12 ft. high, growing on dry, sandy plains, mesas, canyons and hill sides between 2,500 and 5,000 ft. in east Texas and south Kansas to southern and lower California and south into Mexico. Seeds and pods are valuable forage, and two crops of pods can be gathered per year. They are eaten by all livestock, especially horses. Young sprigs are readily browsed in the spring. The honey mesquite is exceptionally drought resistant and withstands heavy grazing, but is very aggressive and must be controlled in pastures. This species is also of value in certain parts of India and the Punjab.

Besides being widespread in America, the common mesquite (*P. juliflora*) is grown in the Sudan, the Orange Free State, south-west Africa, India and Australia. The species *P. velutina*, *P. nigra* and *P. pubescens* have also shown promise in the Orange Free State and southwestern Africa. In some parts of India *P. spicigera* is used and in Iraq the thorny shrub *P. stephaniana* is of some importance on cultivated riverain areas. It also occurs in fields and pastures in the upper plains and mountain valleys of Kurdistan, and forms thickets along the river Tigris, where it covers stretches of otherwise barren country, providing grazing throughout the summer.

Argentina seems to be the centre of polymorphism of this genus, with some 20 good species and a great number of minor forms which cannot be distinguished by nomenclature. There is much material for selection. The best trees for lumber and large sweet pods grow in the north-western provinces. They thrive on clay in semi-arid valleys, but there are also true psammophilous shrubby species, such as *P. alpacato* in Mendoza and *P. argentina* in La Rioja, which are at the same time xerophilous. Another species, *P. ruscifolia*, (the vinal), in the Chaco plains has large leaflets and contains an antibiotic, the alkaloid vinalin. This tree grows on somewhat alkaline soils and has no undergrowth or associated grasses. Although the pods are eaten by livestock, *P. ruscifolia* often becomes too abundant and is considered a pest by stockmen. *P. caldonia*, the caldén of the Pampa province, is a useful tree for timber and forage pods.

PUERARIA: Kudzu

This is largely a tropical genus from East Asia and the Pacific Islands, comprising about a dozen perennial, twining herbs or shrubs with tuberous roots. Some species are very suitable for soil cover

and erosion control, and are also used for hay, pasture and for smothering weeds. In many climates, the kudzus do not set any seed, or set it only very sparingly and are, therefore, often propagated by cuttings.

Tropical kudzu or puero (*P. phaseoloides* = *P. javanica*) is indigenous in the East Indies, but is now grown or has been tested in most tropical countries. In south-east Asia, India, Indonesia, Liberia, French Equatorial Africa and the Belgian Congo, it is grown almost exclusively as soil cover and green manure. Recently, tropical kudzu has also attracted much interest as a pasture and fodder plant. Experiments have been carried out in Puerto Rico, also in other West Indian, Central and South American countries, in tropical Africa, northern India and in Queensland. Generally, it might be stated that these experiments have been very promising in all tropical regions of high and extended rainfall. In those tropical countries with a high rainfall and a not too severe and prolonged dry season, tropical kudzu with its deep-rooting habit keeps green longer than most other legumes and revives with the next rains.

Tropical kudzu is a vigorous, densely pubescent vine. A hairless mutant, recently discovered in Puerto Rico, may be more palatable than the common hairy form. The numerous stolons intertwine and cling tenaciously to the soil, taking root at the nodes and internodes, thus making it an ideal crop for erosion control. It has a deep and widely branching root system, which enables it to withstand drought periods if not too prolonged. It is also tolerant of acid soils and poor soils defective in lime and phosphates, but reacts well to both organic and mineral fertilizers. As already mentioned, tropical kudzu is adapted to a hot and humid climate; it tolerates a high water level in the soil and is best suited to heavier soils, but may succeed on sandy loams.

In Asia and Indonesia, tropical kudzu is mainly used as a cover crop in rubber and oil palm plantations, where it endures at least partial shade. In Malaya, it is often planted with *Centrosema pubescens* (5 lb. *Centrosema* and 2 lb. *Pueraria*) as a cover crop. It is a vigorous climber and must be kept well back from trees, especially when they are young. Seed production is favoured if the plants are allowed to climb. In Ceylon, tropical kudzu has been largely used as a cover under young rubber trees, but has now been replaced by *Desmodium ovalifolium;* the kudzu stands became patchy owing to attacks of an unknown disease. In Zanzibar, tropical kudzu is the best cover crop for clove plantations. In Trinidad, *P. phaseoloides* has given excellent results as a permanent cover for citrus and coconuts. It suppresses the weeds and markedly improves the nitrogen status of the trees. It is best established from seeds sown at about 5 lb. per acre. Pure stands are also used for cut fodder. In Brazil, it is planted in rubber and thrives on soils with a pH-value even as low as 4.2.

When cultivated for forage, tropical kudzu has the following advantages:

(*a*) it is highly palatable once the animals are accustomed to its taste;

(*b*) it is high in protein and yields heavily;

(*c*) when once established, it makes a luxuriant growth and is fairly resistant to trampling;

(*d*) when once established it is relatively drought resistant; it will survive reasonable dry periods and will remain green for at least 2 months after the last effective rains.

Disadvantages are:

(*a*) seed ripening is very uneven and seed harvesting is therefore difficult and exprensive;

(*b*) in many climates, seed setting is poor and cuttings must be used;

(*c*) the plants grow very slowly during the first 3 or 4 months after seeding, and consequently must be carefully cultivated to prevent domination of weeds;

(*d*) seeds must be scarified either in hot water or in sulphuric acid.

When grown for hay, silage or pasture, tropical kudzu may be mixed with different grasses. In Puerto Rico, a mixture with Pará grass (*Panicum purpurascens*), Guinea grass (*Panicum maximum*) or Merker grass (*Pennisetum purpureum* var. *Merkeri*) is recommended. In Jamaica, Dallis grass (*Paspalum dilatatum*) and crab grass (*Stenotaphrum secundatum*) have been successful, in Trinidad, *Ischaemum aristatum*, in Peru, Pará grass (*Panicum purpurascens*) and molasses grass (*Melinis minutiflora*). In some countries, Napier grass (*Pennisetum purpureum*) or jaragua grass (*Hyparrhenia rufa*) are preferred. In Sierra Leone, tropical kudzu is often sown in the rice fields; it increases the yield and smothers the weeds, and provides excellent fodder after the rice harvest.

Tropical kudzu does not stand close grazing or repeated cuts close to the soil surface. When stands are young, care has to be taken not to damage or disturb the long runners when harvesting. Intensive trampling ruins the vines and postpones the regrowth for a considerable time.

The following advice concerning the establishment and management of pastures is given by the Insular Experiment Station, Rio Piedras, Puerto Rico:

" Tropical kudzu may be planted at the same time as Guinea and molasses grasses, or may be seeded into established pastures of these two grasses. The pastures should be grazed closely and furrows ploughed out on the contour every 3 feet. The kudzu should be planted during the rainy season. The seed should be soaked in water for 24 hours, mixed with inoculant and seeded into the furrows. The seed should not be covered if planted during the rainy season. In no case should it be deeply covered. Four pounds of kudzu seed per acre is sufficient to ensure a good stand under moist conditions. The kudzu is rather slow growing during the first months. It may be necessary to graze the grass back to enable the kudzu to come

up rapidly. This should be done before the kudzu plants are very big. Once the kudzu is established, high grazing will favour it until the desired species balance is obtained. Our results indicate that the species balance may be regulated by the height of grazing. Short grazing favours the grass and high grazing the kudzu. High grazing also gives more uniform production throughout the year than short grazing. Five pounds per acre of molasses grass is sufficient to ensure a good stand if well distributed. Guinea grass is best propagated by clumps when viable seed is difficult to obtain. If the latter is available, 8 pounds per acre should be sufficient".

Tropical kudzu is propagated by seeds and cuttings. The seeds must be scarified in hot water or concentrated sulphuric acid (30 mins.). (40,000 seeds/lb.; 5 to 15 lb. are sown in drills or broadcast per acre). Whereas seed is produced readily in many tropical countries (West Indies, Central and South America, Ceylon and Zanzibar), seed settings are nil or very poor in others (Florida, Malaya, Southern Rhodesia and Queensland). In the latter countries, cuttings 3 to 4 ft. long are used; if planted about 3 ft. apart they produce a cover 6 to 9 inches high in 3 to 4 months. Tropical kudzu is little affected by diseases or pests.

Kudzu (*P. thunbergiana* = *P. hirsuta* = *P. triloba* = *Dolichos japonicus* = *Pachyrrhizus trilobus*) is a woody, rooting vine from Japan with leaves resembling those of grapes, also adapted to subtropical and warm temperate climates, and even able to stand winter frosts. The flowers, which are borne in long racemes, are large and purple. Kudzu is a crop for a moderately humid climate and fertile well-drained soils, but is also able to stand protracted droughts. Fertilizers must be added on poor soils. Kudzu is used for erosion control and soil improvement and makes excellent hay and pasture. It takes a long time to establish a good stand, but it is very long-lived. The plant withers during winter and adds a large amount of organic matter to the soil, thus enriching it. With the approach of spring, new growth commences and the plant remains green during the hot summer months and rainy seasons. As seed production is very poor in many countries, it is propagated by both seeds and cuttings. (40,000 seeds/lb.). Scarified seeds are sown in nurseries and the seedlings transplanted, or are sown direct in the field in rows 3 to 4 ft. apart, 6 to 10 lb. per acre.

The best method for vegetative propagation is by planting "crowns" during winter when the kudzu vine sheds all its leaves. A crown is a swollen node, triangular in shape with two or three fleshy roots and a few sound buds. Young crowns one or two years old are better than older crowns. They are planted in pits dug to the size of the roots. If the soil is sandy or light, the crowns must be covered with a thin layer of soil. On heavy soils this is not necessary or desirable. The soil around the crown should be thoroughly packed, and some watering will be needed at first. If watering in the field is impossible, crowns should be planted in pots and kept

moist and protected from hot winds until the rainy season starts, when they can be transplanted in the field.

In the United States and Queensland, cuttings are planted 500 to the acre and other crops cultivated between the rows for the first one or two years. Hay should not be cut before the second year and then not too often, and pasturing should never be very close. Kudzu is cultivated in many sub-tropical countries in the northern and southern hemispheres. Wherever tropical kudzu can be grown, that species should be preferred, but in cooler climates *P. thunbergiana* is the better.

In Puerto Rico, breeding has been started with crosses between *P. phaseoloides* and *P. thunbergiana* in order to combine the adaptation to tropical conditions of the former with the more vigorous growth of the latter. So far no practical results have appeared.

RHYNCHOSIA

This pan-tropic genus has species of some agricultural importance.

R. minima grows wild in Queensland, tropical Africa, Barbados and the Galapagos Islands. It is a strong, creeping perennial with small yellow flowers. In Queensland, it drops its leaves in early winter, but is readily in the young state eaten by farm animals; later it becomes fibrous and coarse; it is important in native pastures, but is a pest in crops. In Kenya, it is only partially palatable. In Barbados, it occurs in meadows with *Andropogon pertusus*. *R. phaseoloides* is found in South and Central America. It had been suspected of being poisonous, but this has been disproved. It is prostrate and rapid in growth and is used for green manure, fodder and human food (beans). Another South American species is *R. lobata; R. elegans* is a palatable African species.

ROBINIA

Robinia pseudoacacia, * black locust, is a thorny, fast-growing tree, sometimes shrub-like, with pinnatifid leaves and comparatively large white flowers in long clusters. It is a plant of eastern North America, but flourishes in the northern temperate zone of the Old World, and thrives on many kinds of soil, even very light sand, provided sufficient nutrients are available and the soil is not too acid. In forestry, this tree is often used to rebuild the fertility of poor sandy soils. After the application, where necessary, of fertilizers and lime, narrow strips of black locust are planted, followed by alternate

broader strips of pine or fir. The great mass of fallen and decomposed black locust leaves considerably improves the nitrogen and organic matter content of the sand and favours the growth of the conifers. This practice is used in Europe and North America. Black locust may also be used for the prevention of erosion on steep slopes. As it is toxic to livestock, it has no value as a fodder tree. Black locust reseeds itself freely and sometimes becomes a pest.

SESBANIA

There are about 20 species in sub-tropical and tropical regions. These herbs, shrubs or small trees are important mainly as green manure, but *S. aegyptiaca*, *S. brachycarpa* and *S. grandiflora* are also used for fodder. In India, Sesbania is a key plant for reclaiming alkaline lands. The species are propagated by seeds.

S. aculeata, native to India where it is called dhaincha, is grown as green manure in many parts of northern India and in West Pakistan (seed rate 40 to 60 lb. per acre). It also grows wild in Queensland and on the south coast of Natal. It is a tall, branching, annual herb adapted to wet areas and heavy soils and sometimes becomes a noxious weed in paddy fields. It is excellent for suppressing *Imperata cylindrica*. *S. aegyptiaca* (= *S. sesban*) is a quick-growing, small tree in South Africa, southern Asia and northern Australia, recommended for temporary shade in *arabica* but not in *robusta* coffee. As it has a shallow root system it competes with the other crops with which it is interplanted. A similar fodder species, *S. brachycarpa*, is grown in Australia. *S. cannabina* is a bushy species recommended for new clearings for rubber and for tea plantations in Ceylon. The hemp Sesbania, *S. exaltata*, is used for green manure in the southern United States (40,000 seeds/lb., 20 to 25 lb. broadcast per acre).

S. grandiflora is a small, fast-growing tree adapted to humid tropical regions, with few branches and long pods which are used for cattle fodder in Indonesia, India, Malaya and Thailand. Flowers, pods and young shoots are used for human food. If the trees are cut back at a suitable height, ample fresh fodder may be obtained throughout most of the dry season. The tree thrives on small paddy bunds even when the paddies are flooded. It also grows well on the very dry western limestone peninsula of Ceylon where the annual rainfall is sometimes not more than 40 inches. It is sometimes planted as a shade tree.

S. macrocarpa, common Sesbania, is a native of North America as far north as Alabama, Georgia and Arkansas. It is mainly a subtropical, upright annual 6 to 8 ft. high, adapted to high soil humidity

but a dry atmosphere. It is rapid in growth, non-palatable and is used for green manure, often on irrigated land. It is sown broadcast or drilled at about 20 lb. per acre. This plant forms root nodules in water. It houses root nematodes, but is undamaged by them. It is, therefore, used freely in potato growing regions where the land can be flooded and the nematodes thus killed. Common Sesbania is often found in rice fields in Louisiana. It has been introduced and tested in Italy for resistance to drought and salinity. This type also appears to be promising in the Sudan. *S. punctata* is very rapid in growth and has given good results as green manure in Indonesia.

In Madras, *S. speciosa* is a valuable green manure in paddy fields. It is very quick-growing (12 ft. high in 3 months), with pithy stems, is free from pests, and can be grown under varied conditions. It is resistant to drought and salinity. Seedlings are raised and transplanted about 6 inches apart in the paddy fields along the margins of the bunds when the plants are 4 to 6 weeks old. The first crop produces over 4,000 lb. of leaves, sufficient to maintain the second crop of paddy. When grown in the second crop, it provides sufficient leaves for the first crop of the next season. Each plant produces about 1/2 lb. (over 9,000) seeds in 4 or 5 months. Vigorous efforts are being made in Madras to show the value of this green manure; it is hoped that its widespread adoption will help to eliminate the problem of rice shortages in this State. *S. speciosa* may be of value in other tropical regions (*see* also *Gliricidia*, p. 274). There are four wild shrubby species in Argentina: *S. punicea*, * *S. virgata* (*S. marginata*), *S. macroptera* and *S. exasperata*, which grow near rivers or swamps and have no forage value. Seed of *S. punicea* is toxic to pigs and poultry (cyanogenetic glucoside).

STIZOLOBIUM: Velvet Beans

The velvet or Mauritius beans belong to several species of the genus *Stizolobium* (formerly *Mucuna*) and to hybrids between them. They are annual-perennial legumes with vigorous vines up to 25 to 50 ft. long (some bushy types exist). The leaves are trifoliolate with large, ovate leaflets. The white to dark purple flowers appear in long pendant clusters. The pods are of two types: with dense black, or white or grey hairs respectively. Pods are 2 to 6 inches long and contain three to six seeds. Velvet beans are native to India, but are now grown in all warm countries. Their distribution has recently been extended into the temperate zones by breeding. They thrive on all soils, even on poor sands and are excellent for soil cover and green manure. The seeds are used as a concentrate, and the stems and leaves for green manure, pasture and fodder.

Velvet beans may be used for the suppression of *Cyperus rotundus* and *Imperata cylindrica.* The vining varieties have to be planted with maize or other crops for support. The harvesting of seed is rather difficult, and pods are usually hand picked; they are then threshed with a flail or in a threshing machine. Velvet beans are largely free from diseases and pests and are drought resistant.

The Florida or Deering velvet bean (*S. deeringianum* syn. *Mucuna pruriens* var. *utilis*), needs 8 to 9 months for ripening in the United States. The Georgia and Alabama varieties are much earlier. Osceola, a hybrid between Florida and Lyon beans (*S. niveum*) is medium-late, whereas the latter species is about as late as Florida. The Chinese velvet bean is similar to Lyon but 6 weeks earlier. The Yokohama bean (*S.hassjoo*) ripens rather early, but has a comparatively low yield and shatters its seeds. The Bush or Bunch varieties do not vine and are about as early as Alabama. Varieties grown in Queensland are: White Mauritius, Black Mauritius, Somerset, Marbilee, Smith and Jubilack. Selections have also been made in Southern Rhodesia; varieties Marbillee, Jubilack, Bengal, White Stingless, Somerset, S. E. S. 30, S. E. S. 45, S. E. S. 68, S. E. S. 74 and S. E. S. 108.

Another species with some promise in tropical countries is *S. aterrimum* (Bengal bean). This drought resistant annual becomes established quickly to give a dense cover which smothers weeds. It is useful as green manure and for rotational grazing under coconuts. It may be grown in pure stands or mixed with other legumes or grasses, or it can be planted between rows of maize or sorghum to provide grazing after the cereal is harvested. In Brazil, Bengal beans are grown mixed with high, erect grasses which are not smothered by the beans (*Panicum barbinode*, *P. maximum* or *Hyparrhenia rufa*). These mixtures yield green fodder, hay and ensilage of excellent quality and crowd out all kinds of weeds. In Brazil, Bengal beans are more persistent and resistant to diseases than velvet beans; they are much used for reviving depleted coffee soils.

Two species are grown to a limited extent in northern Argentina for forage and cover in plantations: *S. cinereum* in sugar cane estates in Salta and Jujuy, and *S. deeringianum* in Misiones in citrus and yerba mate (*Ilex paraguariensis*). In Paraguay, *S. cinereum* is an exceptionally good summer cover and pasture crop; it is sown in October between the rows of ripening maize, and covers the soil rapidly after harvest. At the end of the summer, there is a high mass of foliage which can be pastured by cows or hogs and gives humus and fertility to the soil. In May, it has to be cut down and ploughed under for the next seeding of maize. Seed setting is good, but seed has to be gathered by hand.

S. deeringianum has 1,000 to 1,500 seeds/lb. and 30 to 40 lb. are sown broadcast per acre in the United States. In Northern Rhodesia, the normal practice is to sow the seeds in rows 3 ft. apart, with 1 ft. between plants in the rows, although they may occasionally be sown broadcast. In Queensland, 30 lb. are sown broadcast or 10 lb. per acre in drills 4 to 5 ft. apart.

STYLOSANTHES

Some of these widely distributed tropical herbs or shrubs are valuable pasture plants which combine well with certain grasses and are very drought resistant. *S. bojeri* is an African, prostrate, perennial species, more persistent, frost and drought resistant than *S. gracilis*. It seems promising, but has not so far been tested to any great extent. *S. erecta* is adapted for permanent pastures on sandy soil in Sierra Leone.

S. gracilis or *S. guianensis*, Brazilian lucerne, stylo, is a vigorous perennial 2 to 3 ft. high from tropical South America. It tends to root at the nodes. It has a wide range of adaptability: in Queensland it has been grown successfully on many soil types and seems to thrive both in dry and very wet localities; it tolerates acidity but not swampy conditions. This legume somewhat resembles lucerne in appearance but becomes very woody if allowed to grow large; if kept short it develops into a leafy plant and will remain so for many years. There are various opinions regarding its palatability, but it appears certain that when stock become accustomed to it they graze the plant readily and keep it in the short leafy stage. A large quantity of seeds are produced which mature unevenly. This makes harvesting difficult, but under good conditions the crop can be cut, cured and threshed to provide a fair crop of seed. *S. gracilis* can be readily established from seed in prepared seed-beds or in established pastures. Seeding at 2 lb. per acre is recommended in Queensland. In Southern Rhodesia, this species is drought resistant, and also tolerates light frosts. In Ceylon, it is a good pasture legume for temporary leys in the low country wet zone, where it grows well with *Brachiaria distachya* and *Paspalum dilatatum* and with *Alysicarpus vaginalis*. In grazing trials in Queensland and northern Australia, it thrives with molasses grass (*Melinis minutiflora*), Guinea grass (*Panicum maximum*), Para grass (*Panicum purpurascens*) Kikuyu grass (*Pennisetum clandestinum*) and spear grass (*Heteropogon contortus*), if phosphate is available. It is more productive there than *S. sundaica*. In Brazil, it is used wherever lucerne cannot be grown. In Trinidad, it is an excellent cover for orchards and a promising semi-perennial forage legume; it also seems to be promising in Florida even if it does not set seed. In Hawaii, it is thought highly of and is cut periodically; the variety *subviscosus* from Brazil is also used as a pasture plant under rotational grazing.

S. guianensis is grown also in Fiji and has been successful in pasture mixtures in Kenya and Uganda.

S. hamata is a mat-like perennial plant which volunteers readily in the West Indies and competes well with grasses. In Florida, seed setting is poor and the harvesting of seed difficult; the seeds are enclosed in the leaves as in *Lespedeza*. *S. procumbens* and *S. sundaica* (Townsville lucerne) are found in the sub-tropical pastures of Australia; the latter annual species is a native of South Africa and widely distributed in parts of coastal Queensland and the Northern Territory of Australia. It is adapted to sandy soils and a short summer growing season, and is excellent for pastures with an adequate phosphate status. Seeding rate is 3 to 4 lb. per acre. It prefers soil with a firm base on hard bare areas.

SWAINSONA

There are about 50 species native to Australia and there is one New Zealand species. They are perennial or rarely annual herbaceous, sometimes low, shrub-like plants confined to arid and semi-arid regions. Many species occur below the 10 inch isohyet and all below the 30 inch isohyet. Several species are eaten by sheep, horses and cattle. At least four (*S. galegifolia,* * *S. greyana,* * *S. luteola* * and *S. procumbens* *) are poisonous, causing stock to be " pea-struck ". The poison has not been identified; it appears to be cumulative in action and symptoms may not appear for days or weeks after feeding on the plant has begun. Once having commenced to eat the plants, stock will refuse other food. Symptoms include affected vision, apparent madness, stiff and unsteady gait, loss of weight and eventual death, involving degeneration of the nerve fibres.

Non-toxic varieties are being bred at the Institute of Agriculture, Western Australia, because of the potential value of the genus in semi-arid and arid zones of Australia. A few species (e. g., *S. stipularis*) are considered good fodder plants. *S. salsula** has long rhizomes and tolerates alkalinity. It is recommended for erosion control in the Pacific north-west of the United States; its strong rhizomatous nature makes it a potential weed, and it must be kept under control.

TEPHROSIA

This genus includes woody, erect to semi-prostrate shrubs with deep fleshy roots, sometimes eaten by hogs. The foliage is rather coarse, and usually unpalatable and toxic. The species are, therefore, used almost exclusively for cover and green manure. In Réunion, seeds of *T. candida* are fed to cows in spite of their

reported toxicity, and in Hawaii, *T. purpurea* is said to yield fair fodder but is not recommended for propagation. The species are all propagated by seed (25,000/lb.).

T. candida * is an erect shrub, 4 to 8 ft. high, native to tropical regions, with a wide adaptability, but best suited to moist alluvial soils. It is resistant to pruning and is used extensively for green manure and as hedges, especially on poor soils. In Malaya, the seeds are sown in rows among the main crop (rubber, coconut and oil palms, coffee and tea) at 6 to 7 lb. per acre. If these seeds are planted together in mounds 3 ft. apart, only 3 lb. per acre are necessary. In 4 months, the plants are 3 to 5 ft. high, and at 6 months they are in bloom and require to be pruned to 1 $^1/_2$ ft. above the ground. If pruned twice a year, the plants will last for 4 years. The prunings are dug into the soil, together with lime. If not pruned the plants soon become very woody. *T. candida* thrives in light shade, but dies out in old rubber plantations. As it is susceptible to the so-called pink disease (*Corticium salmonicolor*), which spreads to the rubber trees, many workers do not recommend its use in rubber plantations where this disease is prevalent. It is further affected by pod-boring caterpillars and is susceptible to eelworm. It is used in Nyasaland to provide light shade and green manure in tea plantations and is pruned to form an overhead shade. In coffee plantations and orchards, it is planted as hedges to provide a windbreak. *T. candida* is a popular green manure in Indonesia, but more recently the larger *T. vogelii* has come to be recommended instead. *T. candida* is grown or recommended in Indo-China, Ceylon, Uganda, Sierra Leone, Ivory Coast and Guatemala. In the Orange Free State, it grows wild, interspersed in the Karoo shrubs.

T. purpurea, * fish poison, is an upright bush, 2 to 3 ft. high, native of tropical Asia, Australia and Polynesia. It is grown for green manure in many tropical countries, but is considered inferior to *T. candida*. *T. toxicaria* * is also an erect bush used as green manure in Malaya and Indonesia, but is of little importance. *T. villosa* * is a good green manure in Indonesia but is not used extensively. *T. vogelii* * is a shrub, 8 to 9 ft. high, somewhat larger and requiring better soils than *T. candida*, but rather short-lived. It is used for soil improvement in Malaya, Indo-China, Indonesia, Ceylon and Guatemala. In Uganda, where it grows wild, it is used for temporary shade and as a windbreak in tea and coffee plantations, spaced 8 to 10 ft. apart. When cut back it is short-lived, but when used in a long-term fallow it might last for 4 years or more. In northern Nigeria, it has shown promise in reclaiming land after tin mining. There are 15,000 seeds/lb. When sown in rows 5 ft. apart, about 5 lb. of seed are required per acre. Other species which have been recommended occasionally include *T. barbigera*, *T. ehrenbergiana*, *T. holstii*, *T. hookeriana*, *T. linearis*, *T. noctiflora* and *I. pumila*.

TERAMNUS

Some species of this close relative of *Glycine* have shown promise as pasture plants. *T. uncinatus* is a trailing or climbing perennial vine common in Brazilian pastures. It is leafy, palatable and very drought resistant. In Southern Rhodesia, where it is successful, it has shown good seed setting in the second year of growth, good seed germination, but great susceptibility to frost. *T. labialis* occurs in meadows of *Andropogon pertusus* in Barbados and is also found in Japan. When tested in Kenya, it was found to be palatable to cattle, but not to sheep. Another promising species in Kenya is *T. repens*.

TRIFOLIUM : True Clovers

This genus comprises approximately 250 species; they are mostly native to the humid temperate zone of the Northern Hemisphere, but a few species are indigenous in South America and Africa. Its main centre of origin is believed to be in Asia Minor and south-eastern Europe. Only about 25 species are of agricultural importance; of these, the ten most important species all originated in the Old World. The true clovers are among the most important cultivated plants used for forage and soil improvement in temperate regions, and some have been cultivated for several hundreds of years. They are annual or perennial herbs, mostly adapted to cool and moist climates. In regions with hot and dry summers, their growth in the absence of irrigation is confined to the autumn, winter and spring. They grow best on soils rich in phosphorus, potassium and calcium. Most clovers are long-day plants but there are exceptions.

Most true clovers are trifoliolate and carry the flowers in head-like inflorescences. These heads may have a large number of flowers, as in red clover (upwards of 100) or only a few, as in subterranean clover. Some species (red, alsike and white clover) are almost completely self-sterile and need to be cross-pollinated for seed setting. Others are self-fertile and self-pollinating. The number of seeds per pod varies according to the species, from one to eight.

Red Clover

Trifolium pratense, red, purple or meadow clover or cowgrass, is an upright red-flowered perennial of temperate and sub-arctic regions. Its cultivation has also extended into subtropical regions, at high altitudes or under irrigation. In favourable conditions, a plant may persist for about 7 years, but this is rare. In warmer

climates, its life cycle is often reduced so that it behaves as a biennial or an annual.

The migration and distribution of red clover in Central Europe have been described by Merkenschlager (1934) who drew attention to the numerous regional types which have emanated from a main central line. Three racial groups: (*a*) "Atlantic", made up of early Brabant, Norman and Spanish types; (*b*) " Central Alpine", made up of late flowering types and (*c*) " Continental ", containing late, Greek and Styrian types, can be recognised. The further south the species is found in Europe, the more does it tend to become a plant of the upland region, a natural compensation of increasing altitude for decreasing latitude. As with other legumes, the early history of its cultivation was one of setbacks for many years. Red clover was cultivated in Europe as early as the third and fourth centuries A. D. It was grown in Spain during the 16th century, and subsequently in Holland and Lombardy (Brescia) about the middle of the same century. Nests of cultivation began in Germany, and it was taken from Germany to England in 1650 by a German doctor named Hartlieb, who settled there. It was reported in Russia in 1766.

Red clover was found eventually to occur in many different forms and frequently as characteristic types. Brabant and Styria became in time the centres of production in Europe of the " Atlantic " and " Continental " forms respectively. The term " cow-grass " was applied in England to early flowering red clover. The resistance of farmers and peasants to the introduction of red clover was everywhere marked, as was the case also with potatoes and lucerne. Red clover, like white clover, is now a key plant in most temperate regions with liberal moisture in the summer. The crop is grown alone or in mixtures with grasses and/or other legumes. It is used for the production of hay or silage, also for pasturage, and to some extent for green manure. As a soil improver, it has been of the utmost importance in the agriculture of Europe and parts of North America since its introduction into crop rotations about 100 to 200 years ago.

Red clover is small-seeded (200,000 to 300,000 seeds/lb.); when sown alone, broadcast or in close drills, 8 to 15 lb. of seed are used per acre — even a little more in adverse conditions. In mixtures the rate for red clover is somewhat lower. The seedbed has to be well-prepared and firm, and the seeds must not be drilled too deep. In cooler climates, it is generally sown in spring under a cover crop of cereal; in warmer climates, it is sown in late summer, in the autumn or at the beginning of the wet season.

Two main and one intermediate types are cultivated. Common or double-cut red clover is early, rapid growing, usually less long-lived and less winter-hardy than the others. The medium type is, as its name indicates, intermediate between early and late. The late, mammoth, perennial or single-cut red clover is slow growing, hardy,

and usually more persistent. The major difference between the types is related to photo-periodism or length-of-day response during the growing season. The single-cut types require a longer photoperiod for the initiation of flower primordia. While the single-cut types are generally more tolerant of severe winter weather it is doubtful whether such phenomena relate to selection of the type giving the highest yields in such a climate or if the single-cut type is in itself hardier. Under the conditions of temperature and long-day of higher latitudes, the single-cut types appear to yield more than double-cut types.

It is impossible to treat even briefly all the named strains of red clover; only a few of the best-known are given below:

A. *Double-cut red clovers*

Silesian, a central European, widespread and high-yielding type with many strains.

Broad Red or *Cowgrass*, a local widespread British type, early and non-hardy. Seeds of selected strains are produced in New Zealand.

Mattenklee, a local Swiss strain, early, prostrate and very persistent.

Gendringsche Roode Klaver, a local Dutch strain, rather early and with fine foliage.

Groninger Roode Klaver, a winter-hardy, local Dutch strain, adapted to clay and sandy soils.

Roode Mass Klaver, a high-yielding local Dutch strain, adapted to clay soils.

Roosendaalsche Roode Klaver, a high-yielding local Dutch strain, adapted to sandy soils.

Ötofte Early, from Ötoftegaard, Denmark, early, high-yielding and persistent.

Hjelm, an early and persistent local Danish strain.

Essi, a persistent Swedish variety from the Hammenhög Breeding Station.

Silo, a Swedish variety from the Svalöf Station, medium-early, high yielding and very persistent.

Prinshof Selection, a South African variety, persistent, upright and adapted to irrigation.

Midland, an American variety, adapted to the central part of the Corn Belt, winter-hardy and slightly resistant to northern anthracnose (*Kabatiella caulivorum*).

Kenland, an American variety, adapted to the southern part of the growing area in the United States, highly resistant to southern anthracnose (*Colletotrichum trifolii*), but not to the northern (*Kabatiella caulivorum*); rather persistent.

Dollard, bred at McDonald College, Canada, adapted to the Province of Quebec and north-western United States; resistant to northern anthracnose (*Kabatiella caulivorum*).

Ottawa, bred at the Central Experimental Farm, Ottawa, adapted to northern latitudes and moderate rainfall; very resistant to *Sclerotinia* spp. and leaf hoppers.

B. *Medium red clovers*

Vale of Clwyd, a local British type with later and more persistent strains than common Broad Red Clover.

Dorset Marl, a British strain with similar characteristics.

S. 151, from the Welsh Plant Breeding Station, persistent and with comparatively dense growth.

Ötofte Medium-Late, a high-yielding, persistent Danish variety from Ötoftegaard.

Karaby, a south Swedish, high-yielding and rather persistent local strain.

Merkur, from Svalöf, high-yielding, resistant to stem rot (*Sclerotinia trifoliorum*) and eelworm (*Anguillulina dipsaci*).

Resistenta, a Swedish variety from W. Weibull similar to Merkur.

C. *Single-cut red clover*

Montgomery Late, a local British type, winter-hardy and winter-dormant, with dense growth. Seeds of selected strains are produced in New Zealand.

Cornish Marl *Cotswold* late-flowering red *Essex* late-flowering red *Suffolk* late-flowering red	Raise similar British strains

S. 123, produced by the Welsh Plant Breeding Station, spreading pasture type and low dense growth, very persistent.

Göta, a Swedish hardy variety from A. Holmberg and Sons.

Ultuna, a winter-hardy, persistent, central Swedish local strain.

Offer, a winter-hardy, persistent, north Swedish local strain.

Molstad, a local Norwegian strain, late and winter-hardy.

Toten, a similar Norwegian strain, still later than Molstad.

Tammisto, a Finnish variety from the Tammisto Station, winter-hardy and resistant to *Sclerotinia trifoliorum.*

Altaswede, from the University of Alberta, Canada, winter-hardy but not drought resistant.

Manhardy, a Canadian winter-hardy variety, adapted to humid sections of the Province of Manitoba.

Alsike Clover

*Trifolium hybridum** resembles red clover in growth habit, but has pink flowers, is softer and more slender and is better adapted to moist conditions. It is grown in the temperate and sub-Arctic zones of Europe, Asia and North and South America, but is not adapted to warm climates. Alsike clover is grown for the same purposes and in the same way as red clover, but has never acquired such great importance. Under the growth conditions prevailing in northern Europe, Canada and some northern states of the United States it is, however, a valuable complement to red clover in hay fields, and to white clover in pastures and meadows. The variation within this species is much narrower than in *T. pratense*. Some naturally selected local strains are found, however, especially in Scandinavia. The Swedish Seed Association, Svalöf, has produced a variety, Svea, adapted to central Sweden, and W. Weibull, Ltd., have marketed a tetraploid, high-yielding and persistent variety called Tetra. The Danish Plant Breeding Station, Otofte, has produced a high-yielding variety; Ontario Agricultural College, Guelph, Ontario, has a variety called Alon.

The seeds of alsike clover are very small, about 700,000/lb.; 6 to 10 lb. are sown per acre, broadcast or densely drilled. In mixtures, as mostly used, the seeding rate is about 2 to 5 lb. an acre. Methods for sowing are as for red clover.

Alsike clover is sometimes cyanophoric.

White Clover

Trifolium repens * is a creeping, white-flowered perennial with prostrate stems rooting at the nodes. It is an excellent pasture plant growing wild or cultivated in all temperate climates where there is enough moisture. It stops growing when hot and dry weather sets in, but usually revives when conditions again become favourable. White clover is preferably used in pastures, but is also suitable for hay and silage. It improves the soil where it is grown. In the temperate zones, white clover is the most important pasture legume. It is generally grown mixed with grasses, but exceptions occur in Europe and North America. In the United States, Ladino clover is often grown in a pure stand.

There are many natural and a number of bred strains of white clover, which can be divided into three main groups; the small-leaved or wild white, the medium-leaved or common, and the large-leaved or Ladino types. Generally speaking, the first type is most prostrate and most adapted to grazing, but is rather low in yield and has short stems; the last type is taller and coarse and is also used for haymaking. The common white clover is intermediate. Ladino clover is a north Italian type which has recently become popular in central Europe and parts of the United States, where there is ample moisture, natural or artificial.

The small-leaved type, which has short stolons and small flower heads, is most common in old pastures which have been intensively grazed for a long time. Local strains of this type have been named after the region of origin (Kentish, North Swedish, etc.). The Welsh Plant Breeding Station has produced a persistent variety based on this type, S. 184.

The common or intermediate type comprises local strains, some of which have received attention and have been marketed (the Dutch Witte Weideklaver and Witte Weideklaver C. B., the Danish Morsö and Strynö, and the Victorian Irrigation in Victoria, Australia). Selected and bred varieties include the Danish Otofte Morsö, the Swedish Hero, Nora and Robusta, the Welsh S. 100, the Canadian Duron and Pathfinder, and the New Zealand Certified Strain.

The large-leaved Lodi or Ladino type with long stolons and large flower heads consists of local north Italian strains, which have developed under irrigation. They are robust and have long upright

leaf-stalks and peduncles. The Otofte Station in Denmark has produced a selection, Otofte Lodi, but beyond this no bred strains have been put on the market.

There are 750,000 seeds/lb. All three types have the same seed size. For a pasture mixture 4 to 10 lb. are usually sown, but smaller amounts are often adequate. White clover reseeds itself and spreads by runners.

Some strains of white clover are cyanophoric.

Crimson Clover

Trifolium incarnatum, crimson, carnation, French or Italian clover, is an upright annual with bright, red, large conical flower heads. It is not hardy and is grown in the Mediterranean area, central Europe, the United States, Argentina and other countries for hay, pasture, cover or green manure, often as a catch crop. In cooler climates it is used as a summer annual, in warmer climates as a winter annual. Crimson clover is adapted to light, sandy and clay soils which are not too acid, but it is not very drought resistant. It tolerates more acidity than white and red clover. There are 140,000 seeds/lb. and 12 to 15, sometimes 20 lb., are sown per acre (broadcast or densely drilled).

Seed of common crimson clover germinates immediately after ripening, as soon as adequate moisture is present. This is an undesirable characteristic, as germination will occur after light rains and the seedlings may die when the soil dries again. Breeding has been carried out in the United States to obtain varieties which will produce volunteer stands. The following are now available:

Dixie, a mixture of equal parts of three strains selected for resistance to early germination in spring when grown as a winter annual. It has a high percentage of hard seeds and produces volunteer stands successfully in the autumn, when moisture conditions are more reliable. This variety is widely grown in the south-eastern United States.

Auburn, a variety selected from a volunteer stand in Auburn, Alabama, also produces good volunteer stands when followed by crops of grain sorghum, Sudan grass, Johnson grass, soyabeans or permanent pastures.

Other strains are: Autauga, a farm strain originating in Autauga County; *Alabama*, similar to Dixie, but slightly earlier in maturity; *Talladega*, another farm strain from Alabama, but slightly later than the others.

Subterranean Clover

Trifolium subterraneum is a European, self-regenerating annual grown in Australia and New Zealand south of latitude 30° S., in the Pacific north-west and the southern states of the United States, parts of South America (Uruguay, Argentina) and in the winter rainfall area of South Africa. It is mostly used as a winter annual in temperate climates on moderately acid to neutral soils. Phosphorus must be provided if not available. Subterranean clover thrives best in areas with long, warm winters and dry summers. It is primarily a pasture plant, but is also important as a soil improver. Subterranean clover is not very palatable up to the flowering stage and stock neglect it almost entirely. This greatly favours its dominance in heavily grazed pastures, at least in the early phases, when the available nitrogen supply of the soil is still low. From about the flowering stage onwards the clover may be grazed quite heavily, especially in old pastures. Pastures which have been grazed lightly or not at all may be cut for hay. The seeds provide an excellent protein concentrate for sheep during the dry summer months in Australia. When the seed is ripening, the plant buries the inflorescences in the soil, so giving the species its name. It is not a very drought resistant clover, but dry summers are " escaped ", since the seeds remain dormant both through lack of summer rains and because the seed coats are variable in hardness. The stand for the subsequent season is assured by a dense growth of seedlings which follow the rains of the autumn or early winter. There are many strains of varying earliness, adjusted to various growth periods, all first described in Australia. There are about 65,000 seeds/lb.; 20 to 35 lb. are sown broadcast per acre in the United States, but in Australia only 1 to 5 lb. per acre is used.

The following Australian varieties are given in order of earliness:

Dwalganup, a local strain of the Department of Agriculture, Western Australia, very early, with long, sparsely leaved runners; adapted to regions with annual rainfall of 17 to 30 inches and a growing period of 5 1/2 to 6 months.

Bacchus Marsh, a local strain distributed by the Department of Agriculture, Victoria; early, leafy, with long runners; adapted to regions of about a 20 inch rainfall and a growing period of 7 months.

Mount Barker, the first local strain discovered in South Australia; mid-season type, leafier than the early strains, with long runners; adapted to regions with annual rainfall of about 21 inches or more, and a growing period of at least 7 1/2 months.

Tallarook, a local strain of the Department of Agriculture, Victoria; late, very leafy, much branched, with short runners;

adapted to regions of at least 25 inches rainfall and a growing period of 8 1/2 to 9 months; does not escape summer drought as well as the others.

Nangeela, slightly later than Tallarook; spreading rapidly in the United States.

These strains make their growth over a period when surface moisture is available more or less continuously and temperatures do not inhibit growth for significant periods of time. This period is also one of relatively short days, 6 months at least with photoperiods of 12 hours or less, falling to about 9 hours in mid-winter. According to the length of this effective rainfall period, an earlier or later strain is employed; but in all cases survival of the species depends upon the formation of viable seeds before the onset of acute summer drought. The seeds of an early maturing strains may thus remain dormant for 5 to 6 months at least, while those of a later strain may remain dormant only for 3 to 4 months.

Berseem

Berseem or Egyptian clover (*Trifolium alexandrinum*) is a most important legume of the Mediterranean and Near East countries and of India. It probably originated in Asia Minor and was introduced through Syria and Palestine to Egypt where it is now grown extensively (7,700,000 acres). It has also spread east to India, and has recently attracted interest in regions in North and South America and South Africa. Berseem is also grown in Sicily and southern Italy, either as a dryland crop during the winter or as an irrigated crop, sown in the spring or the summer after the wheat has been harvested. It is non-hardy, grown mostly as a winter annual and generally under irrigation. It has trifoliolate leaves with oblong leaflets, round yellowish white flower heads and a rather deep root system for an annual. It thrives in a temperate but not too hot climate, does not stand severe frosts and needs an annual rainfall of at least 10 inches. It usually produces two to three cuts in a growing season, but may, with irrigation, give up to 7 to 8 cuts in 8 to 10 months. Berseem is tolerant of relatively high salt concentrations and can be grown on alkaline soils (up to 0.6 per cent.). It produces best on heavy loams, but will also grow quite well on light soils.

Berseem starts growth with remarkable vigour and, when properly irrigated 10 days before cutting, makes a quick recovery after defoliation and produces abundant, palatable and nutritious forage. It responds to small quantities of phosphate also, to lime when the soils is deficient. Berseem is mostly used for green fodder and hay.

The succulent stems with their high water content are, however, difficult to dry and the leaves drop very easily in the dry state. It is used to some extent for silage, and, in Egypt, frequently for pasture.

The different types of Berseem are Fahli, a tall dry land variety giving only one cut; Saidi, deep-rooted and drought resistant, mostly grown in Upper Egypt, where it is sown after the Nile floods and gives 2 to 3 cuts without irrigation; Khadrawi, a high-yielding variety for irrigation (4 to 7 cuts) and rather late; Miskawi, the best Egyptian variety, especially with winter irrigation, is fast growing and provides many cuts.

Berseem has about 200,000 seeds/lb. In Egypt and South Africa, 45 to 60 lb. are sown broadcast per acre; in India and Pakistan 20 to 40 lb. are recommended; in Italy, if drilled, 20 to 25 lb. and in the United States 15 to 20 lb. per acre.

In Egypt, berseem is often infected by *Orobanche*, and is an important alternate host of the cotton leaf worm (*Prodenia litura*). In Argentina, a locust (*Schistocerca cancellata*) causes great damage.

Other Clovers

Persian clover (*Trifolium resupinatum* or *T. suaveolens*), sometimes called annual strawberry clover or shaftal from Central Asia, resembles berseem and is grown as a winter annual in the Near East, the cooler parts of India, and to some extent in the southern states of the United States for hay and pasture. It is adapted to wet situations on rendzina-type soils in south-eastern South Australia, and is there called annual strawberry or birds eye clover. It is not winter-hardy, lodges easily and prefers deep heavy soils. There are 675,000 seeds per lb. and 4 to 6 lb. are sown broadcast per acre (U. S. A.).

Strawberry clover (*T. fragiferum*), sometimes called strawberry-headed clover or trefoil, is a European perennial similar in growth habit to white clover. This clover is so called because its fruiting head is somewhat similar in shape to a strawberry. It is adapted to pastures in temperate climates with limited or no summer drought and tolerates salinity and high soil moisture. Apart from its area of origin, it is also occasionally grown in pastures in Australia, New Zealand, South Africa and the north-western United States. It associates well with *Phalaris tuberosa;* in such mixtures the Palestine strain is adapted to grazing by sheep. Strawberry clover has about 300,000 seeds per lb. and 6 to 10 lb. are sown broadcast per acre.

A few characteristic Australian strains are recognised:

Palestine, introduced by Dr. H. C. Trumble of Adelaide, in 1929, from Rhodesia, where it had been acquired from Palestine; large leaflets and robust stolons, develops more vigorous-

ly in winter than other strains; has a lax growth habit and flowers in the spring; adapted to light and heavy soils, frost, resistant.

Shearman's, a local strain in New South Wales, vigorous and large-leaved, but poor in seed setting; dormant in winter, makes most growth in summer; adapted to fertile, marshy and saline soils and under moist conditions also to lighter soils; frost resistant; propagated vegetatively.

Swan Hill and *Columna*, local, leafy vigorous and summer flowering strains, adapted to most fertile and saline soils; frost resistant.

Large hop clover (*T. campestre* = *T. procumbens*) and small hop clover (*T. dubium*) also called hop trefoil, are small-leaved annuals with yellow flowers in small heads. They are of some importance as volunteer species in pastures of temperate climates. In cool regions they are summer, in warmer regions winter, annuals; in the latter case they provide early spring growth. They tolerate rather unfavourable soils. In 1 lb. of seed there are about 2,000,000 seeds of large hop clover and about 1,000,000 of small hop clover; 3 to 5 lb. of seed are sown per acre.

Other species of *Trifolium* are of some value in certain regions and for certain purposes, e. g. *T. africanum*, *T. agrarium* (yellow or hop clover), *T. alpinum*, *T. amabile*, *T. ambiguum* (Kura clover), *T. arvense* (rabbit foot clover), *T. badium*, *T. burchellianum*, *T. carolinianum* (Carolina clover), *T. cheranganiensis* (in East Africa), *T. glomeratum* (cluster clover), *T. hirtum* (rose clover), *T. johnstonii* (Kenya wild white clover), *T. lappaceum* (lappa clover), *T. macrocephalum*, *T. montanum*, *T. nigrescens* (ball clover), *T. pannonicum* (Hungarian clover), *T. parviflorum* (small-flowered clover), the South American *T. polymorphum*, *T. pratense nivale*, *T. reflexum* (buffalo clover), *T. semipilosum* (in East Africa) and *T. striatum* (striata clover).

TRIGONELLA: Fenugreek

Trigonella foenum graecum belongs to a genus which comprises about 75 species of annual or rarely perennial herbs native to the Old World (India, Near East and Abyssinia). There is also one Australian species. They are mostly low plants with trifoliolate leaves.

Fenugreek is an annual herb grown as a condiment or pot herb, also for fodder and soil improvement in the Mediterranean countries and east to southern U. S. S. R., and India, in California, and in

parts of the tropics. It is either sown in spring or in autumn, depending upon the climate. In India it is usually a cold season crop cultivated with or without irrigation. In Upper India and the Punjab, it is used as a green fodder crop and as a soil renovator; sown in June or July, it ripens in 2 1/2 to 3 months. In California, it is a winter green manure. In the Sudan, it is grown in small patches under irrigation as a winter crop; the wild species, *T. hamosa* and *T. laciniata*, form dense stands similar to lucerne and are considered good fodder plants. In the U. S. S. R., fenugreek is sown either in spring or in autumn, and is considered good cattle fodder, with high protein content and nutritive value. In Sicily, fenugreek may be grown mixed with oats and vetches for fodder.

There are about 23,000 seeds/lb. per acre and 25 to 35 lb. are sown broadcast in the United States. In India, 15 to 20 lb. per acre are considered enough for a non-irrigated pure crop; in other cases, 40 lb. per acre are recommended.

In South Australia, a wild species, *T. ornithopodioides* is common in wet, swampy localities, and grows well without any phosphatic fertilizers. An annual herb in flooded localities of the Queensland arid sub-tropics is *T. suavissima*.

ULEX: Gorse or Furze

This genus includes about 30 species of spiny shrubs. Only gorse (*Ulex europaeus*), * which is of Mediterranean origin, has any practical value. It is a spiny bush, 2 to 7 ft. high, which covers sandy and rocky land in western and southern Europe and which has spread to North America, Argentina, New Zealand and Hawaii. It is browsed by goats and sheep, particularly in the young state. It was formerly considered to be a winter feed for cattle and horses, and was sown for this purpose on poor sandy soils. Now, however, it is frequently a pest.

VICIA: Vetches

There are about 150 species in the temperate zones, annual or perennial herbs, climbing by tendrils. All vetches grown commercially are cool temperature annuals of European or west Asiatic origin, grown as summer or winter annuals depending upon climatic conditions. The vines are used for hay, silage, pasture, soil cover and green manure, and the seeds as concentrates. In cooler climates, vetches are often grown mixed with cereals for fodder and seed production. Most vetches are weak-stemmed and semi-winding. The leaves are pinnate with terminal tendrils. The flowers are self-

fertile and mostly of a light or dark lavender colour; the inflorescences are racemes. The pods are linear, never inflated, and when ripe burst open readily. Vetches tolerate soil acidity and can be grown successfully on gravelly soils. Little breeding has so far been done. Most strains grown commercially are naturally selected local varieties.

The most important type is common or spring vetch, or tares (*V. sativa*). It has low winter hardiness and is thus grown as a summer annual in cooler climates, and as a winter annual in warmer climates. Seeds are produced in many countries, more especially in central Europe and in Oregon, in the United States (Willamette vetch). Common vetch is a rather long, twining herb (3 to 7 ft.) and is widely used for green fodder and as a concentrate in Europe. In North America, it is an important green manure on poor land. The seed size varies but there are generally about 8,000 seeds/lb. and 50 to 80 lb. are sown per acre.

Some authorities consider that vetches have a great future in India for fodder and green manure. The local vetch (*V. sativa*) has been considered a weed in cultivated areas, but it is an excellent fodder of high protein content, it grows naturally without irrigation and covers the soil completely. It can be either cut, grazed or ploughed in as green manure. This crop may be safely introduced in areas where generally only Kharif (summer) crops are taken. For example, in the rice tracts where the need for good fodder is acute, this or other legumes which propagate by reseeding themselves may be important. In certain places in Uttar Pradesh and Madhya Pradesh, vetches are already being used as a forage crop.

In South America, common vetch grows well in the Buenos Aires province of Argentina, where it is sometimes sown with cereals for winter pasture. Recently a mixture of 40 to 50 lb. per acre of this vetch with 10 to 12 lb. per acre of *Phalaris minor* was strongly recommended for the north of the province. With some care in spring, both reseed well for a second year with only a light tillage in the autumn.

Next in importance is perhaps the hairy or winter vetch (*V. villosa*), which includes some glabrous strains called smooth vetch. This is the hardiest of the vetches, and can be sown in autumn even in regions with cold continental winters. It is adapted to sandy soils and tolerates both alkalinity and acidity. Seeds are produced in the Baltic region of Europe, South Africa and in Michigan and Oregon, in the United States. Seeds of smooth vetch are grown in North Carolina. It is a hay, green fodder and soil improving crop. There are about 16,000 to 18,000 seeds/lb. and 30 to 40 lb. are sown per acre.

Another important species which differs from most of the others, in having a thick, erect, non-branching stem and no tendrils, is *V. faba* (= *Faba vulgaris*), the broad or horse bean, field or tick bean. *V. faba* can be divided into the sub-species *eu-faba* with the two forms,

major and minor, characterized by large and small seeds respectively, and the sub-species *paucijuga*, comprising several Indian forms. It is grown in Europe, Egypt, South Africa, India, China, North, Central and South America and other countries, mainly for its edible seeds, but also for green fodder and hay; the seeds are used as a concentrate for livestock, especially in the Mediterranean region where it is native. The seed size varies widely (500 to 3,000 seeds/lb.) and seed sown per acre may be 70 to 320 lb.

An erect vetch of importance mainly in southern Europe and the Near East is the ervil or bitter vetch (*V. ervilia* = *Ervum ervilia*). * It has small, conical seeds used for stock feed, although in larger amounts they are somewhat poisonous. The seed rate is about 70 lb. per acre.

Another hardy, early vetch in central Europe is the Hungarian vetch (*V. pannonica*). It is adapted to heavy clay and is also grown in the United States (Oregon). Seeds are produced in southern Europe. There are about 10,000 seeds/lb. and 70 to 80 lb. are sown broadcast per acre.

V. articulata, the monantha or one-leaved vetch, is similar to hairy vetch, but less hardy. It is grown to some extent in the western and southern United States and is adapted to well-drained clay for sandy soils of fairly good fertility and abundant moisture. It is good for hay and early pasturage, and the seeds are also used for human food. Seeds are produced in southern Europe. There are about 12,000 seeds/lb. and seed rates are between 30 and 80 lb. per acre.

The narrow-leaved or Augusta vetch (*V. angustifolia*) resembles common vetch but is smaller, very tolerant of acid soils, and is used in the southern United States and South Africa for soil improvement and pasture. It has shown promise for sowing in semi-wild pastures of Argentina. It has a high percentage of hard seeds and therefore volunteers readily. It succeeds as a cultivated plant only in mixture with grasses. Seeds are produced in the United States and South Africa, (30,000 seeds/lb.; seed rate 30 to 40 lb. per acre broadcast). A close relative is purple vetch (*V. atropurpurea* = *V. benghalensis*) grown on the Pacific coast of the United States where seeds are also produced. It possesses poor winter hardiness, is earlier than *V. villosa*, and grows on poorer soil than *V. sativa*. It is also used to some extent for pasture in Argentina. Seed size and rate are as for *V. angustifolia*. A fairly winter-hardy species is *V. dasycarpa*, woolly pod vetch, used in Oregon as hairy vetch. Bigflower vetch (*V. grandiflora*) has promise as winter cover in the United States, and reseeds freely, but seed is sparse. The narbonne vetch (*V. narbonensis*) is similar to *V. angustifolia* and is sometimes grown for fodder and green manure in southern Europe. *V. tenuifolia*, a perennial herb spreading by rhizomes, has shown promise on cut-over and burnt-over areas

in the United States. South American species of value in pasture mixtures in sub-tropical climates are *V. graminea*, *V. nigricans*, *V. obscura*, *V. selloi* and *V. montevidensis*.

VIGNA: Cowpea

This genus comprises about 60 species which were formerly included under *Dolichos* and of which only two or three are grown for fodder. They are herbs of warm and tropical countries; most are annuals, but there are also some perennials. The cowpeas originated in Central Africa, but were early introduced to all countries with a suitable climate in both the Old and the New World, including Australia. Their adaptation resembles that of maize, but they need more heat and grow in almost any soil. Cowpeas are deep-rooted, vigorous, herbaceous and winding. They are useful for smothering *Imperata cylindrica*. They are a useful crop because they do not mature in a definite period, but continually produce new leaves if cut back regularly from an early stage.

The annual *Vigna sinensis* (= *V. unguiculata*) is the most common species. Probably *V. sesquipedalis* and *V. catjang* are only sub-species of *V. sinensis*. *V. sesquipedalis* (asparagus bean, yard-long bean) has long kidney-shaped seeds and long, shrivelling, pendant pods, whereas *V. catjang* (catjang) has short erect pods and small cylindrical seeds. All have trifoliolate leaves similar in shape to those of common garden beans, but they vary widely in size. There are many varieties of this old cultivated plant, each adapted to special climatic and soil conditions. The cowpeas are used for human food, as concentrates for farm animals, hay, silage (mixed with sorghums), pasture, soil cover and green manure. The harvesting of seed is costly because of the uneven ripening of the pods. In America, machines constructed for this purpose cut the vines under the soil surface. The whole crop is later collected, dried and threshed. In South Africa, a variety of bunched growth habit was produced from which seeds are readily harvested. In India, cowpeas are grown both pure and as a mixed crop, and both as an early or late monsoon crop or as a hot weather crop under irrigation (special varieties). In Ceylon, cowpeas have been employed more as cover in rubber plantations than any other species. In Sicily, cowpeas are grown for forage on irrigated land in succession to wheat or other principal crops. In Zanzibar, cowpeas are grown in rotation with rice and turned in. The cowpea is sown to a limited extent in northern Argentina. In Paraguay and Venezuela, it is an important food plant because it is there less susceptible to pests and diseases than the common beans (*Phaseolus vulgaris*).

The cowpeas are sensitive to cold, but resistant to drought and heat. Because of attacks of fungous diseases, they are unsuited

to humid areas. The cowpeas have many enemies, such as insect, pests, rust, mildew, anthracnose, root nematodes, etc. The variety Iron is most resistant to the common fungus diseases and to nematodes. The seed size varies greatly; for this reason, also because of the different purposes for which the crop is grown, the seed rate also varies. For seed, cowpeas are sown in rows 3 ft. apart, for forage, broadcast or sown in rows 6 to 8 inches apart. In India and Pakistan, the seed rate is 40 to 60 lb. per acre.

North American varieties grouped according to characters are:

(*a*) *Seeds flattened round* (*Crowders*): Mush, Purple Hull Crowder, Red Crowder, Small Lady, Smith No. 14 Speckled Crowder, Sugar Crowder, Withe Crowder, William Crowder, William Hybrid,

(*b*) " *Striscianti* " *Creeping:* Conch, Red Eye, William Hybrid.

(*c*) *Decumbent:* Colico, Congo, Large Lady, Lilac Red Pod, New Era, Pony, Red Crowder, Red Pipper, Saddleback, Small Lady.

(*d*) *Semi-decumbent:* Black, Black Eye, Blue Hull, Chocolate, Constitution, Everlasting.

(*e*) *Erect:* Clay, Coffee, Quadroon, Red, Unknown, Wippoorwill, Wonderful, Brabham.

(*f*) *Very early:* Very Early, Chocolate, Congo, New Era, Vacuum, Withe Giant.

(*g*) *Early:* Granite, Red Crowder, Red Eye, Red Yellow Hull, Saddleback, Smith No 7.

(*h*) *Medium-early:* Coffee, Large Lady, Lilac Red Pod, Mush, Pony, Small Lady, Smith No. 7.

(*i*) *Late:* Black Eye, Everlasting, White Crowder, William Hybrid.

(*j*) *Very Late:* Black, Blue Hull, Colico, Clay, Conch, Forage, Shiny, Gourd, Taylor, Prolific, Wonderful, Unknown.

Varieties grown in Queensland are:

Poona Pea, erect when young, later prostrate, not very drought resistant, susceptible to wilt and nematodes. Seed rates: broadcast 15 to 20 lb.; in drills 2 1/2 ft. apart 5 to 8 lb. per acre.

Reeves, bushy growth habit, similar to Poona Pea but wilt-resistant.

Giant or Mammoth, vigorous running habit, susceptible to wilt and nematodes. Seed rates: broadcast 40 to 50 lb.; in drills 2 1/2 ft. apart 12 to 15 lb. per acre.

Groit, semi-upright, fine-stemmed, susceptible to wilt and nematodes.

Cristando, similar to Poona Pea, but higher resistance to wilt.

Victor, half-bushy growth habit, otherwise similar to Poona Pea. Seed rates: broadcast 25 to 30 lb.; in drills 2 11/2 ft. apart 8 to 10 lb. per acre.

A species from the East Indies, the Sarawak bean, (*Vigna oligosperma* = *V. hosei*) is grown mainly as a cover and green manure, and forms a dense cover in a short period. As it has a shallow root system, it thrives in low situations, but it can also adapt itself to extremely dry conditions. It grows in the deep shade of rubber trees. In mature rubber cuttings, it may be planted 6 ft. apart in prepared beds and will produce complete cover in 6 months. The Sarawak bean is cultivated in Indonesia, Indo-China, Malaya, Ceylon, Queensland and other tropical countries in both the Old and the New World. It is propagated by seeds or cuttings (17,000 seeds/lb.). A seeding rate of 3 lb. per acre is recommended in Queensland.

In the Sudan, the roots of *V. vexillata* are used as a substitute for sweet potatoes. In Nicaragua, this species grows wild in the pastures on the Atlantic coast. It also occurs in Southern Rhodesia, Kenya, West Africa and Queensland. It has a vigorous growth habit with abundant foliage on long trailing or climbing vines, and a strong perennial root. It produces plenty of seed, which germinates well. The species may have possibilities as a pasture or fodder plant.

V. reticulata is recommended in French Equatorial Africa for smothering *Imperata cylindrica*. It contains much crude fibre and is, therefore, not good for green manure. Seeds are sparse and difficult to harvest.

VOANDZEIA

The Bambarra groundnut, Madagascar peanut, Juga bean or earth pea, *V. subterranea*, is a native of Africa. It is a low, short-lived, creeping herb with branched stems and pinnately trifoliolate leaves. The flowers are small, and the pods are pushed into the soil as in the case of groundnuts. The pods are hard and contain one hard, round seed. *V. subterranea* thrives in poor soils, but does best in a hot climate and on sandy or sandy-loamy soil with a fair amount of lime and organic matter. The Bambarra groundnut is widely cultivated in Africa and is often grown in crop rotations in South Africa with maize and sorghum. The method of cultivation is as for groundnuts. Yields are similar to those of the groundnut but the seeds are lower in fat and protein, and higher in cellulose. They are used either green or ripe for human consumption; when ripe, they have to be boiled or ground. They may also be used as feed for livestock.

ZORNIA

Zornia is a small genus with one polymorphous species (*Z. diphylla*) which is pan-tropic; the other species are mainly American, and one is found in Africa (Cape and Angola). They are herbs with equally pinnate, often punctate, leaves. The pods are compressed, the upper suture nearly straight, the lower deeply sinuated, the articulations are indehiscent, smooth or echinate.

Z. diphylla has stems a foot or more long, slender, herbaceous, glabrous, diffusedly branched at the base. Stipules are lanceolate, petioles $^1/_2$ to $^3/_4$ inch long, the leaflets in a single pair at the apex, lanceolate. Flowers appear 6 to 8 together in lax, axillary, stalked racemes, 2 to 3 inches long, hidden each by a pair of persistent bracts, which are ovate and rigid. This species is the most common legume of the Amazon region of Brazil, and is also common in other South American countries (Venezuela, Colombia, Argentina). In Africa it is known from Nigeria, Sierra Leone, Loanda, Nubia, Abyssinia, Uganda and Mozambique in dry grassland and exposed rocky places. In the Sudan, it covers big areas and is of considerable importance as a fodder plant. In many African countries, horsekeepers prepare a good hay as provender for the dry season. *Z. diphylla* has shown promise as a fodder plant in the Sudan and Queensland.

BIBLIOGRAPHY

In compiling this bibliography it has not been possible to include more than a few publications from the very extensive literature on all aspects of the subject. The list includes publications to which reference is made in the text together with some other works which were frequently consulted. In the preparation of Part II considerable use was made of the bibliographical information provided in Herbage Abstracts.

AIYER, A. K. YEGNA NARAYAN. Mixed Cropping in India. *Indian J. Agric. Sci.* 1949, Vol. 19, Pt. 4, pp. 439-543.

____________________. Field Crops of India. 3rd ed. 1950, pp. XXI + 686, Bangalore Press.

ÅKERMAN, A. et al. Svalöf 1886-1946. History and Present Problems. 1948, pp. 388, Carl Bloms Boktryckeri A.-B, Lund.

ALBRECHT, W. A. Physiology of Root Nodule Bacteria in Relation to Fertility Levels of the Soil. *Proc. Soil Sci. Soc. Amer.* 1937, Vol. 2, pp. 315-27.

ALLEN, O. N. AND ALLEN, ETHEL K. A Survey of Nodulation among Leguminous Plants. *Proc. Soil Sci. Soc. Amer.* 1942, Vol. 12, pp. 203-8.

ANDERSON, A. J. AND SPENCER, D. Molybdenum and Sulphur in Symbiotic Nitrogen Fixation. *Nature* 1949, Vol. 164, pp. 273-4.

BENNETTS, H. W. et al. A Specific Breeding Problem of Sheep on Subterranean Clover Pastures in Western Australia. *Aust. Vet. J.* 1946, Vol. 22, pp. 2-12.

BERTRAND, G. AND SILBERSTEIN, L. Nouvelles déterminations de la teneur en bore de plantes cultivées sur le même sol. *C. R. Acad. Sci.* 1937, Vol. 204, pp. 1019-21.

BJÖRLING, K. Undersökningar rörande klöverrötan. I. Infektionsförsök med *Sclerotinia trifoliorum* Eriksson. (Investigations Concerning Clover Stem Rot. I. Infection Trials with *Sclerotinia trifoliorum* Eriksson). 1939, *Stat. Växtskyddsanst. Medd.* No. 27, pp. 1-24.

BLACKMAN, G. E. The Interaction of Light Intensity and Nitrogen Supply in the Growth and Metabolism of Grasses and Clover (*Trifolium repens*). I. The Effects of Light Intensity and Nitrogen Supply on the Clover Content of a Sward. *Ann. Bot.* N. S. 1938, Vol. 2, pp. 257-80.

——— AND TEMPLEMAN, W. G. Same publication. II. The Influence of Light Intensity and Nitrogen Supply on the Leaf Production of Frequently Defoliated Plants. *Ann. Bot.* N. S. 1938, Vol. 2, pp. 765-91.

BROUN, A. F. AND MASSEY, R. E. Flora of the Sudan (with a Conspectus of Groups of Plants and Artificial Key to Families, by J. Hutchinson). 1929, pp. 512, Sudan Government Office London.

BUNTING, B. AND MILSUM, J. N. Cover Crops and Green Manures. *Malay Agric. J.* 1928, Vol. 16, No. 7, pp. 256.

BURKART, A. La Flora Argentina y la Producción Fourrajera. (The Argentine Flora and Forage Production). Anales del Instituto Popular de Conferencias, 1944. Diario *La Prensa*, Buenos Aires, Argentina.

———. Las Leguminosas Argentinas, Silvestres y Cultivadas. (Wild and Cultivated Legumes of Argentina). 1943, pp. 620, Istituto de Botanica Darwinión, San Isidoro, Argentina (1952).

CHEN, H. K. AND THORNTON, H. G. The Structure of "Ineffective" Nodules and its Influence on Nitrogen Fixation. *Proc. Roy. Soc.* Ser. B. 1940, Vol. 129, pp. 208-29.

CHEVALIER, A. Recherches sur les espèces du genre *Cyamopsis*, plantes fourragères pour les pays tropicaux et semi-arides. (Research on Species of the Genus *Cyamopsis*, Forage Plants for Tropical and Semi-arid Countries). *Rev. Bot. Appl.* 1939, Vol. 19, pp. 242-49.

COCHRAN, W. G. AND COX, G. M. Experimental Designs. 1950, pp. IX + 454, bibl., John Wiley and Sons, Inc. New York.

CODD, L. E. AND MYBURGH, S. J. *Glycine javanica* as a Soil Conserving Legume. *Fmg. S. Afr.* 1949, Vol. 24, pp. 471-2.

CODD, L. E. et al. A Useful Winter Fodder Plant, Berseem Clover. *Fmg. S. Afr.* 1949, Vol. 24, pp. 422.

COMMONWEALTH AGRICULTURAL BUREAUX. Joint Publication 6. Alternate Husbandry. 1948, pp. 157.

COMMONWEALTH BUREAU OF PASTURES AND FIELD CROPS, ABERYSTWYTH. *Bull.* 3. The Technique of Breeding Herbage Plants. 1931, pp. 77, 3 pl.

———. *Bull.* 12. Lucerne, its Ecological Position and Distribution in the World. By M. Klinkowski. 1933, pp. 61, bibl.

———. *Bull.* 31. The Provision of Animal Fodders in Tropical and Sub-tropical Countries (West Indies, Hawaii, Fiji, Gold Coast, and Southern Sudan, Zanzibar, Rhodesia). 1944, pp. 84.

———. *Bull.* 32. Advances in Grassland Husbandry and Fodder Production (in South Africa, New Zealand, U. S. A., Szechwan, China). 1st symposium. 1944, pp. 108.

———. *Bull.* 34. The Establishment and Early Management of Sown Pastures. 1945, pp. 210, 93 plates.

———. *Bull.* 35. The Forage Resources of Latin America. El Salvador. By J. M. Watkins. 1946, pp. 24, illus.

———. *Bull.* 36 The Grasslands of Latin America. By G. M. Roseveare. 1948, pp. 291.

———. *Bull.* 38. Advances in Grassland Husbandry and Fodder Production, 1947, pp. 83.

———. *Bull.* 39. Five Hundred Varieties of Herbage and Fodder Plants. By M. Hall. 1948, pp. 328.

———. *Bull.* 41. Management and Conservation of Vegetation in Africa. 1951, pp. 97, 38 illus., 5 maps.

———. *Herb. Publ. Ser. Bull.* 18. Pasture and Forage Crops in South Africa. By I. B. Pole Evans and A. R. Saunders. 1936, pp. 30, 6 figs.

———. *Herb. Publ. Ser. Bull.* 21. The Influence of Climatic Conditions on Type Composition. By N. Sylvén. 1937, pp. 8.

———. *Herb. Publ. Ser. Bull.* 26. Research on Grassland, Forage Crops and the Conservation of Vegetation in the U. S. A. 1939, pp. 113.

COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH, AUSTRALIA. Pastures of Australia. The Australian Environment. By C. S. Christian et al. 1949, pp. 97-124.

———————— . *Bull.* 99. A Survey of Pastures of Australia. (Includes ecological information and discussions of the pasture map of the Commonwealth). By A. McTaggart. 1936, pp. 71.

———————— . *Bull.* 105. Investigations in the Associated Growth of Herbage Plants. By H. C. Trumble et al. 1937, pp. 40, 10 pl.

DE SORNAY, P. Les légumineuses. (The Leguminosae). *Rev. Agric. Maurice.* 1937, No. 91, pp. 1-3.

DHARMANI, L. C. AND SINGH, A. A Study of the Chemical Composition and Yield of Berseem (*Trifolium alexandrinum*) as Influenced by the Intervals Between Cuttings. *Indian J. Agric. Sci.* 1946, Vol. 16, pp. 287-90.

DU TOIT, J. J. The Role of Lucerne on Irrigation Settlements. *Fmg. S. Afr.* 1950, Vol. 25, pp. 13-16.

DUTT, C. P. AND PUGH, B. M. Farm Science and Crop Production in India. 1947, pp. 240, Allahabad.

EDWARDS, D. C. AND BOGDAN, A. V. Important Grassland Plants of Kenya. 1951, pp. 124, bibl. illus., Isaac Pitman and Sons, Nairobi.

ENGLAND AND WALES. MINISTRY OF AGRICULTURE AND FISHERIES. Grassland Management. 1952. *Bull.* No. 154, pp. 67.

FERTILIZER SOCIETY, LONDON. Proc. 8. Role of Fertilizers in Increasing Output from Grassland. By R. A. Hamilton. 1950, pp. 52, 3 figs.

FISHER, R. A. et al. The Design of Experiments. 4th ed. 1947, pp. 239, London; Oliver and Boyd.

FRANDSEN, K. J. Studier over *Sclerotinia trifoliorum* Eriksson. (Studies on *Sclerotinia trifoliorum* Eriksson). English summary. 1946, pp. 220, 109 figs. Det Danske Forlag, Copenhagen.

FOOD AND AGRICULTURE ORGANIZATION, ROME. *Agric. Stud.* 16. Improving the World's Grasslands. By A. T. Semple. 1951, pp. 147.

GATES, R. R. Epigeal Germination in the Leguminosae. *Bot. Gaz.* 1951, Vol. 113, No. 2, pp. 151-157.

GROBBELAAR, W. A. Cultivation of Dryland Lucerne. *Fmg. S. Afr.* 1950, Vol. 25, pp. 234.

GUSTAFSSON, ÅKE. Mutations in Agricultural Plants. *Hereditas*, 1947, Vol. 33, pp. 1-100.

HARLAN, J. R. New World Crop Plants in Asia Minor. *Sci. Mon.* 1951, Vol. 72, No. 2, pp. 87-89.

HAWAII AGRICULTURAL EXPERIMENT STATION. *Bull.* 93. Legumes of the Hawaiian Ranges. By E. Y. Hosaka and J. C. Ripperton. 1944, pp. 80.

———————— . *Bull.* 100. Koa Haole (*Leucaena glauca*), its Establishment, Culture and Utilization as a Forage Crop, with Notes on other Legumes. By M. Takahashi and J. C. Ripperton. 1949, pp. 56.

HENNING, P. D. The Culture and Utilization of Dryland Lucerne in the Winter Rainfall Area of South Africa. *Brit. Agric. Bull.* 1950, Vol. 3, pp. 93-97.

HOFMEYER, J. H. Dryland Lucerne and Soil Improvement in the Grain Areas of the Winter Rainfall Area. *Fmg. S. Afr.* 1946, Vol. 21, pp. 797-802.

HOLLAND, T. H. Alternative Green Manure Plants. *Trop. Agriculturist, Peradeniya.* 1931, Vol. 76, pp. 135-136.

———— . The Green Manuring of Tea, Coffee and Cacao. II. *Trop. Agriculturist, Peradeniya* 1931, Vol. 77, pp. 71-99.

HUDSON, P. S. New Plants for Old. *Sci. Mon.* 1949, Vol. 69, No. 6, pp. 404-407.

HUITEMA, W. H. AND HEETEREN, H. V. A. The Economic Gardens at Bogor. Guide and Outline of the Most Important Crops. Contribution No. 1. 1943, Bogor.

INTERNATIONAL CROP IMPROVEMENT ASSOCIATION. Publication 12. Minimum Seed Certification Standards. 1950.

KLAGES, K. H. W. Ecological Crop Geography. 1942, pp. 633, Macmillan; New York.

LAUBSER, J. T. A. The Cultivation of Dryland Lucerne. *Fmg. S. Afr.* 1951, Vol. 26, pp. 291-293.

LEONARD, L. T. A Failure of Austrian Winter Peas Apparently due to Nodule Bacteria. *J. Amer. Soc. Agron.* 1930. Vol. 22, pp. 277-279.

Loock, E. E. M. Three Useful Leguminous Fodder Trees. *Fmg. S. Afr.* 1947, Vol. 22, pp. 7-12 and p. 27.

Malaya Department of Agriculture. *Agric. Ser. Leaflet* 6. Cover Crops. 1934, p. 4

——————. *Agric. Ser. Leaflet* 7. Green Manures. 1934, pp. 5.

——————. *Sci. Ser. Leaflet* 24. Fodders and Feedingstuffs in Malaya. By Sunn Lay Teik. 1951, pp. 11 + 88.

McCalla, T. M. Behaviour of Legume Bacteria (*Rhizobium*) in Relation to Exchangeable Calcium and Hydrogen Ion Concentration of the Colloidal Fraction of the Soil. *Res. Bull. Missouri Agric. Exp. Sta. 256.* 1937, pp. 44.

Merkenschlager, F. Migration and Distribution of Red Clover in Europe. *Herb. Rev.* 1934. Vol. 2, pp. 88-92.

Milton, W. E. J. and Davies, R. O. The Yield, Botanical and Chemical Composition of Natural Hill Herbage Under Manuring, Controlled Grazing and Hay Conditions. *J. Ecol.* 1947, Vol. 35, pp. 65-95.

Nakata, S. Photoperiodic Response of *Lespedeza. Plant Physiol.* 1952, Vol. 27, pp. 644-647.

Nilsson-Leissner, G. Rödklöverförsök på klöverrötsjord vid Svalöf. (Red Clover Trials at Svalöf on Soil Infected with Clover Stem Rot). *Sveriges Utsädesför. Tidskr.* 1942, pp. 352-363.

——————. Testing New Plant Materials for Re-vegetation of Grazing Lands. *Proc. U. N. Sci. Conf. Conserv. and Utiliz. Resources.* Vol. VI Land Resources. 1951, pp. 530-534, New York.

Nutman, P. S. Genetical Factors Concerned in the Symbiosis of Clover and Nodule Bacteria. *Nature* 1946, Vol. 157, pp. 463-465.

——————. Physiological Studies on Nodule Formation. I. The Relation Between Nodulation and Lateral Root Formation in Red Clover. *Ann. Bot.* N. S. 1948, Vol. 12, pp. 81-96.

——————. Physiological Studies on Nodule Formation. II. The Influence of Delayed Inoculation on the Rate of Nodulation in Red Clover. *Ann. Bot.* N. S. 1949, Vol. 13, pp. 261-283.

Ochse, J. J. Vegetables of the Dutch East Indies. 1931, pp. xxxvi + 1005, illus., van Riemsdyck, The Hague, The Netherlands.

Organization for European Economic Co-operation. Pasture and Fodder Development in Mediterranean Countries. Technical Assistance Mission No. 56. 1951, pp. 176, Paris.

Overholt, W. W. A Preliminary Study of Some Soil-improving Crops for Fukien. *Fukien Agric. J.* 1949, Vol. 11, Nos. 1 and 2, pp. 61-66.

Parham, B. E. V. List of Introduced Leguminous Plants Recorded in Fiji. *Agric. J., Fiji.* 1949, Vol. 20, pp. 21-26.

Pereverzev, G. A. A New Valuable Plant, *Crotalaria. Sovet. Not.* 1940, No. 4, pp. 46-56.

Piper, C. V. Forage Plants and their Culture. 1942, pp. 639, Macmillan, New York.

Robinson, D. H. Leguminous Forage Plants. a 2nd ed. 1947, pp. vii + 126, Edward Arnold and Co, London.

Rose, M. F. Possible Crops for the Cotton Rotation in the Southern Jebels Area of Kordofan. *Emp. Cott. Gr. Rev.* 1950, Vol. 27, pp. 260-274.

Rowland, J. W. The Use of Perennial Leys in Farming Rotations. Parts. 1 and 2. *Fmg. S. Afr.* 1951, Vol. 26, pp. 9-13 and 52-57.

Sellschop, J. Groundnuts. *Fmg. S. Afr.* 1947, Vol. 22, pp. 705-712.

Skibbe, A. and Sellschop, J. Some Fodder Plants and Feeding Stuffs: Their Culture and Chemical Composition. *J. Dep. Agric. S. Afr.* 1922, Vol. 4, pp. 338-339.

Smith, R. M. et al. Organic Matter and Nitrogen Build-ups in some Puerto Rican Soil Profiles. *Soil Sci.* 1951, Vol. 72, pp. 409-427.

South Africa Department of Agriculture. *Sci. Bull.* 124. The Fodder Trees of the Broken Veld (Fauresmith District). By M. Henrici. 1940.

——————. *Bull.* 170. Lucerne in South Africa. By H. W. Turpin and D. W. McKellar. 1937, pp. 88.

——————. *Bull.* 240. Soyabeans in South Africa. By A. R. Saunders. 1943, pp. 58.

——————. *Bull.* 268. Dryland Lucerne for the Winter Rainfall Area. By J. T. R. Sim. 1945, pp. 14.

SOUTH AFRICA DEPARTMENT OF AGRICULTURE. *Bull.* 270. Agro-economic Survey of the Union. I. Introduction and Description of the Highveld Cropping Areas. 1948, pp. 192, maps.

——————————— . *Bull.* 275. Agro-economic Survey of the Union. II. The Five Cropping Areas of the Winter Rainfall Area. 1949, pp. 108.

——————————— . *Bull.* 289. Agro-economic Survey of the Union. III. The Drakensberg Grazing Areas. (n. d.), pp. 59.

——————————— . *Bull.* 309. Agro-economic Survey of the Union. IV. The Mixed Farming Areas East of the Drakensberg. 1949, pp. 120.

——————————— . *Bull.* 320. A Key to the Agro-economic Map of the Union of South Africa.

STRONG, T. H. The Influence of Host Plant Species in Relation to the Effectiveness of the *Rhizobium* of Clovers. *J. Coun. Sci. Industr. Res.* 1937, Vol. 10, pp. 12-16.

——— . The Establishment of Pastures on Deep Sands in the Upper South-east of South Australia. Appendix to *Bull. Coun. Sci. Industr. Res. 122.* 1938, pp. 23-24.

——— . Legume Establishment and its Function in Relation to the Development of Some of the Poor Soils on Kangaroo Island. *J. Dep. Agric. S. Aust.* 1938, Vol. 41, pp. 542-550.

THIMANN, K. V. On the Physiology of the Formation of Nodules on Legume Roots. *Proc. Nat. Acad. Sci.* 1936, Vol. 22, pp. 511-514.

THOMSON J. R. Sainfoin in its First Harvest Year. *J. Brit Grassl. Soc.* 1951, Vol. 6. pp. 107-117.

——— . Seed Studies in Sainfoin. *J. Brit. Grassl. Soc.* 1951, Vol. 6, pp. 147-159.

THORNTON, H. G. A Suggested Explanation of the "Inefficiency" of Certain Strains of *Rhizobia*. *Trans. 3rd Internat. Congr. Soil Sci.* A. 1939, pp. 20-23.

——— . Report of the Department of Soil Microbiology for the Years 1939-45. 1947, pp. 21. Gibbs and Barnforth, Ltd., St. Albans, England.

TIDBURY, G. E. Rice Cultivation of Land Between Successive Crops. *E. Afr. Agric. J.* 1947, pp. 212-214.

TOTHILL, J. D. et al. Agriculture in Uganda. 1940, pp. XVI + 551, 9 figs, 30 pl., maps and charts. Oxford University Press, London.

TRUMBLE, H. C. AND STRONG, T. H. Investigations on the Associated Growth of Herbage Plants. Paper 1. On the Nitrogen Accretion of Pasture Grasses when Grown in Association with Legumes. *Bull Coun. Sci. Industr. Res.* 105. 1937, pp. 11-24.

TRUMBLE, H. C. et al. Report of the F.A.O. Mission to Nicaragua. 1950, pp. 200. (available in Spanish only, English edition out of print. 1952).

TURPIN, H. W. AND ROWLAND, J. W. A Mixed Farming System for the Highveld. *Fmg. S. Afr.* 1951, Vol. 26, pp. 145-147.

UMBREIT, W. W. Three More Reasons for Soybean Inoculation. *Soybean Dig.* 1944, Vol. 4, No. 6, pp. 9-10.

UNITED STATES DEPARTMENT OF AGRICULTURE. Yearbook of Agriculture. Grass 1948, pp. XIV + 892, Washington. U.S.A.

——————————— . *Misc. Publ.* No. 101. Important Western Browse Plants. By W. A. Dayton. 1931, pp. 213.

VAVILOV, N. J. Theoretical Bases of Plant Breeding. Vol. 1. Sect, 1. The Phytogeographical Basis of Plant Breeding. 1935, pp. 1,060, Leningrad.

WARD, H. M. On the Tubercular Swellings on the Roots of *Vicia faba*. *Phil. Trans. Roy. Soc.* (B). 1897, Vol. 178, pp. 539-562.

WELSH PLANT BREEDING STATION. ABERYSTWYTH. *Bull. Ser.* H. 12. Clovers. By R. D. Williams. 1931, pp. 180-240.

——————————— . *War Food Prod. Adv. Bull*, 3. Herbage Seed Production. By G. Evans. 1944, pp. 30, bibl.

WHEELER, W. A. Forage and Pasture Crops. 1950, pp. XI + 752. Macmillan, New York.

WHYTE, R. O. The Significance of Forage Crops in Canadian Agriculture. *J. Brit. Grassl. Soc.* 1950, Vol. 5, pp. 21-35.

——— , AND YEO, M. L. Green Crop Drying. 1952, pp. 328. Faber and Faber, London.

WILSIE, C. P. Seed Production Studies with Legumes in Hawaii. *J. Amer. Soc. Agron.* 1935, Vol. 27, pp. 784-790.

Wilson, J. K. Leguminous Plants and their Associated Organisms. *Mem. Cornell Univ. Agric. Exp. Sta. 221.* 1939, pp. 48.

__________. Over Five Hundred Reasons for Abandoning the Cross-inoculation Groups of the Legumes. *Soil Sci.* 1944, Vol. 58, pp. 61-69.

Wilson, P. W. The Biochemistry of Symbiotic Nitrogen Fixation. 20 pl., 1940, pp. 316. Madison, Wisconsin, U. S. A.

Wipf, Louise, and Cooper, D. C. Chromosome Numbers in Nodules and Roots of Red Clover, Common Vetch and Garden Pea. *Proc. Nat. Acad. Sci.* 1938, Vol. 24, pp. 87-91.

Woodroffe, K. Investigations of the Soil Fertility Problem in the Wheatlands of South Australia. *Proc. Brit. Commonw. Sci. Off. Conf. Aust.* 1949, 1951, pp. 425-436. H. M. S. O. London.

APPENDIX

Characteristics of Herbaceous and Shrubby Legumes

Genus	Species	Plant Characters: Annual	Biennial	Perennial	Erect	Prostrate	Winding, trailing	Toxic	Somewhat toxic	Drought resistant	Climatic Adaptation: Polar and sub-polar zones	Temperate and sub-temperate zones: Extended rainfall	Winter rains only	Summer rains only	Tropical and sub-tropical zones: Extended rainfall	Restricted rainfall	Irrigation	Arid and sub-arid	Soil Adaptation: Light soils	Heavy soils	Calcareous	Shallow	Well-drained	Moist	Alkaline	Acid	Utilization: Green and conserved fodder	Pasture	Concentrates, human food	Green manure, soil cover	Erosion control	Number of Seeds per lb.	Seeding Rates lb. per acre, broadcast	Notes
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
Acacia	*farnesiana*			x	x					x					x	x		x										x						
	moniliformis			x	x					x			x	x		x		x										x	x					
	victoriae			x	x					x			x	x		x		x										x	x					
	villosa			x	x					x					x	x														x				
Adesmia	*bicolor*			x		x	x			x					x	x		x		x								x						
Aeschynomene	*americana*			x	x								x	x	x	x				x				x			x	x		x		160 000	40	
Alysicarpus	*vaginalis*	x		x	x	x									x	x							x				x	x		x		300 000	10-20	
	vaginalis var. *nummularifolius*	x		x	x	x									x	x							x					x				300 000	10-20	
Anthyllis	*vulneraria*			x	x	x				x	x	x							x		x	x			x		x	x		x		175 000	15-20	
Arachis	*hypogaea*	x			x	x									x	x	x		x				x				x	x	x	x		1 000-1 200	20-30 (hulled seeds) 30-50 (hulled seeds)	U.S.A. in rows 3-4 ft. apart. India double amount.
	glabrata			x		x									x	x			x									x				great		Propagation by rhizomes
Astragalus	*chinensis*			x	x	x									x	x				x			x							x	x	130 000	20-25	
	cicer			x		x			x	x		x	x					x				x						x		x	x	130 000	20-25	
	falcatus	x				x			x	x		x	x				x	x	x			x						x				130 000	20-25	
Cajanus	*cajan*			x	x					x					x	x		x	x								x	x	x	x		8 000	15-20 (8-10)	Rows 3-4 ft. apart
Calopogonium	*mucunoides*			x	x	x									x	x								x			x	x	x	x		30 000	3	Australia; 5-8 in rows, 13-5 ft. apart.
Canavalia	*ensiformis*	x			x		x		x	x					x	x	x										x		x	x		great	35-60 8 (spaced)	Central America spaced 2-3 ft. each way
	gladiata	x				x	x	x		x					x	x											x		x	x				
Cassia	*didymobotrya*			x	x				x						x	x												x		x				
	hirsuta			x	x			x							x	x														x				
	leschenaultiana			x	x			x							x	x														x		110 000		
	occidentalis	x	x	x	x			x							x	x														x				
	pumila			x	x	x		x							x	x														x	x			
	siamea			x	x				x						x	x											x			x				
	tora	x			x	x		x							x	x		x									x			x		22 000	40-45	
Centrosema	*plumieri*	x		x		x	x			x					x	x												x		x		2 500	3	in rows 3 ft. apart
	pubescens			x		x	x			x					x	x		x					x				x	x		x	x	18 000	4-5	in rows 3 ft. apart
Cicer	*arietinum*	x			x				x	x			x	x	x	x	x			x			x				x		x	x		1 000	30-40 (20-30)	spaced (3-4) x (3-4) ft.
Clitoria	*cajanifolia*			x	x										x	x														x	x	13 000		
	ternatea			x		x	x								x	x	x											x		x				
Crotalaria	*anagyroides*			x	x					x					x	x										x				x		25 000	20-30	6-10 in rows 3-5 ft. apart
	goreensis			x	x			x		x					x	x										x				x			10	
	grantiana	x			x				x						x	x	x									x				x		150 000	10-13	
	incana			x	x										x	x										x	x	x		x		85 000	15-18	3-4 in rows 3-4 ft., apart
	intermedia	x			x										x	x	x									x	x	x		x		100 000	10-15	
	juncea	x			x				x	x					x	x	x									x	x	x	x	x		15 000	35-40	(up to 80 lb.)
	lanceolata			x	x										x	x										x	x	x		x		170 000	8-12	2-3 in rows 3-4 ft. apart

Genus	Species	Plant Characters									Climatic Adaptation								Soil Adaptation								Utilization					Number of Seeds per lb.	Seeding Rates lb. per acre, broadcast	Notes
SPECIES		Annual	Biennial	Perennial	Erect	Prostrate	Winding, trailing	Toxic	Somewhat toxic	Drought resistant	Polar and sub-polar zones	Temperate and sub-temperate zones: Extended rainfall	Temperate and sub-temperate zones: Winter rains only	Temperate and sub-temperate zones: Summer rains only	Tropical and sub-tropical zones: Extended rainfall	Tropical and sub-tropical zones: Restricted rainfall	Irrigation	Arid and sub-arid	Light soils	Heavy soils	Calcareous	Shallow	Well-drained	Moist	Alkaline	Acid	Green and conserved fodder	Pasture	Concentrates, human food	Green manure, soil cover	Erosion control			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
Crotalaria	*mucronata*			x	x										x	x										x	x	x		x		75 000	10-20	5-6 in rows 5 ft. apart
	spectabilis			x	x			x		x					x	x			x							x				x		30 000	20-30	4-6 in rows 3-4 ft. apart
	usaramoensis			x	x										x	x										x				x		160 000	8-12	2-3 in rows 3-4 ft. apart
Cyamopsis	*psoralioides*	x			x					x			x	x	x	x	x										x	x	x	x		20 000	30-40	10 in India; 60 in Sind
	senegalensis	x				x				x						x		x	x									x						
	stenophylla	x				x				x						x		x	x									x						
Cytisus	*prolifer*			x	x					x			x	x		x		x										x						
	stenopetalus			x	x					x			x	x		x		x										x						
Desmanthus	*virgatus*			x	x										x	x											x	x		x				
Desmodium	*adscendens*			x			x								x	x								x				x		x				spaced 3 x 3 ft.
	barbatum			x		x									x	x										x		x						
Desmodium	*canum*			x		x									x	x								x		x		x		x				
	discolor			x	x										x	x								x		x		x						
	gangeticum	x													x	x											x	x		x				
	gyroides			x	x	x									x	x														x		110 000		
	heterophyllum			x		x									x	x												x		x			3	Australia
	nicaraguensis			x	x					x					x	x											x	x		x				
	rensonii			x	x										x	x												x		x				
	salicifolium			x	x										x	x								x		x	x	x						
	scorpiarus			x		x									x													x					1-2	Australia
	tortuosum	x			x								x	x	x	x			x							x	x	x		x		200 000	8-10	
	triflorum			x		x	x								x	x											x	x		x				
	uncinatum			x	x	x									x	x				x				x		x		x						
Dolichos	*biflorus*	x			x	x	x			x					x	x			x			x				x	x		x	x			40	
	bulbosus			x		x	x		x						x	x											x			x				
	lablab			x		x	x		x						x	x											x	x	x	x		1 400	20-25	rows 3-4 ft. apart
Galega	*officinalis*			x	x				x				x			x			x	x						x	x			x		62 000	20-25	
Glycine	*javanica*			x			x								x	x											x	x		x				
	max	x			x		x			x		x	x	x	x	x			x					x			x	x	x	x		variyng	vayring	
Hedysarum	*coronarium*			x	x	x				x			x				x				x		x		x		x	x				100 000	20-35	
Indigofera	*arrecta*			x	x				x	x					x	x														x				
	endecaphylla			x		x	x		x	x					x	x										x	x	x		x		200 000		spaced 2 x 2 ft. or 4 x 4 ft.
	hirsuta	x		x	x	x	x		x				x	x	x	x			x							x	x	x		x		200 000	8-10	
	pilosa	x				x							x	x	x	x			x	x										x	x			
	retroflexa			x	x					x					x	x											x	x		x				
	suffruticosa			x	x										x	x												x		x				
	sumatrana			x	x										x	x														x				
	tinctoria			x	x										x	x														x		150 000		

Characteristics of Herbaceous and Shrubby Legumes *(continued)*

Genus	Species	Plant Characters: Annual (1)	Biennial (2)	Perennial (3)	Erect (4)	Prostrate (5)	Winding, trailing (6)	Toxic (7)	Somewhat toxic (8)	Drought resistant (9)	Climatic Adaptation: Polar and sub-polar zones (10)	Temperate and sub-temperate zones: Extended rainfall (11)	Winter rains only (12)	Summer rains only (13)	Tropical and sub-tropical zones: Extended rainfall (14)	Restricted rainfall (15)	Irrigation (16)	Arid and sub-arid (17)
Lathyrus	*cicera*	×	×	×	×	×	...	...	×	×	...	...	×	×	...	...	...	...
	hirsutus	×	...	...	×	×	...	×	...	...	...	...	×	×	...	...	...	...
	ochrus	×	...	...	×	×	...	...	×	...	...	...	×	×	...	...	...	...
	sativus	×	...	...	×	...	...	...	×	...	...	...	×	×	×	×	...	...
	silvestris	...	...	×	...	×	...	×	...	...	...	×	×	×	...	...	...	...
	tingitanus	×	...	...	×	×	...	×	...	×	...	...	×	×	...	×	...	...
Lens	*esculenta*	×	...	...	×	...	...	...	...	...	...	×	×	×	×	×	×	...
Lespedeza	*cuneata*	...	...	×	×	...	...	...	...	×	...	...	×	×	×	×	...	...
	stipulacea	×	...	...	×	×	...	...	...	×	...	...	×	×	×	×	...	...
	striata	×	...	...	×	×	...	...	...	×	...	...	×	×	×	×	...	...
Leucaena	*glauca*	...	...	×	×	...	...	×	...	...	...	...	...	...	×	×	...	...
	pulverulenta	...	...	×	×	...	...	×	...	...	...	...	...	...	×	×	...	...
Lotus	*corniculatus*	...	...	×	×	×	...	...	×	...	...	×	×	×	×	...	...	...
	hispidus	...	...	×	...	...	×	...	...	×	...	...	×	×	...	...	...	...
	tenuis	...	...	×	×	×	...	...	×	...	...	×	×	×	...	...	...	...
	tetragonolobus	...	...	×	...	×	...	...	...	...	...	...	×	×	...	...	...	...
	uliginosus	...	...	×	×	×	...	...	×	...	...	×	×	×	...	...	...	...
Lupinus	*albus*	×	...	...	×	...	...	...	×	...	...	×	×	×	×	×	...	...
	angustifolius	×	...	...	×	...	...	...	×	...	...	×	×	×	...	...	...	...
	hirsutus	×	...	...	×	...	...	...	×	...	...	×	×	×	...	...	...	...
	luteus	×	...	...	×	...	...	...	×	...	...	×	×	×	...	...	...	...
	pilosus	×	...	...	×	...	...	...	×	...	...	...	×	×	...	...	...	...
	polyphyllus	...	...	×	×	...	...	...	×	...	...	×	×	×	...	...	...	...
Lupinus	*tassilicus*	×	...	...	×	...	...	...	×	...	...	...	×	×	...	×	...	...
	termis	×	...	...	×	...	...	...	×	...	...	...	×	×	...	×	...	...
Medicago	*arabica*	×	...	...	×	×	...	...	...	...	...	...	×	...	...	...	...	...
	falcata	...	...	×	...	×	...	...	...	×	×	×	...	...	...	...	...	...
	hispida	×	...	...	×	×	...	...	...	...	...	...	×	...	...	...	...	...
	lupulina	×	×	...	×	×	...	...	...	...	×	×	×	×	...	...	...	...
	minima	×	...	...	×	×	...	...	...	...	...	...	×	...	...	...	...	...
	orbicularis	×	...	...	×	×	...	...	...	...	...	...	×	...	...	...	...	...
	rigidula	×	...	...	×	×	...	...	...	...	...	...	×	...	...	...	...	...
	sativa	...	...	×	×	...	...	...	...	×	...	×	×	×	...	×	×	...
	scutellata	×	...	...	×	×	...	...	...	...	...	...	×	...	...	...	...	...
	truncatula	×	...	...	×	×	...	...	...	...	...	...	×	...	...	...	...	...
Melilotus	*alba*	×	×	...	×	...	...	...	×	×	...	×	×	×	...	...	...	...
	indica	×	...	...	×	...	...	...	×	×	...	×	×	×	...	×	×	...

Genus	Species	Soil Adaptation: Light soils (18)	Heavy soils (19)	Calcareous (20)	Soallow (21)	Well-drained (22)	Moist (23)	Alkaline (24)	Acid (25)	Utilization: Green and conserved fodder (26)	Pasture (27)	Concentrates, human food (28)	Green manure, soil cover (29)	Erosion control (30)	Number of Seeds per lb. (31)	Seeding Rates lb. per acre, broadcast (32)	Notes
Lathyrus	*cicera*	×	...	...	×	...	...	...	...	×	...	...	×	...	8 000	60-70	
	hirsutus	×	...	...	...	...	×	...	×	×	×	...	×	...	15 000	50-60	20 lb. drilled in rows
	ochrus	...	...	...	...	...	...	...	...	×	...	...	×	...			
	sativus	...	×	...	...	...	...	...	...	×	...	×	×	...	5 000	70-80	U.S.A.; 20-40 in Pakistan
	silvestris	...	...	...	...	...	...	...	...	×	×	...	...	×	8 000	60-70	
	tingitanus	×	...	...	×	...	...	...	...	×	×	...	×	...	5 000	60-80	8-30 lb. in Algeria
Lens	*esculenta*	×	×	...	...	...	...	...	...	...	...	×	×	...	9 000	30-80	12-15 in rows 3-4 ft., apart
Lespedeza	*cuneata*	...	×	...	...	...	...	...	×	×	×	...	×	×	350 000	10-15	hulled
	stipulacea	...	...	...	...	...	...	...	×	×	×	...	×	×	225 000	10-15	unhulled
	striata	...	...	...	...	...	...	...	×	×	×	...	×	×	370 000	8-10	unhulled
Leucaena	*glauca*	...	×	...	...	×	×	...	...	×	×	×	×	×	12 000		
	pulverulenta	...	×	...	...	×	×	...	...	×	×	...	×	...	25 000		
Lotus	*corniculatus*	...	...	×	×	...	×	...	×	×	×	...	...	...	325 000	5-8	
	hispidus	...	...	...	...	...	...	...	...	×	×	...	...	...			
	tenuis	...	...	×	×	...	×	...	×	×	×	...	...	...	350 000	5-8	
	tetragonolobus	...	...	...	...	...	...	...	...	...	...	×	...	...			
	uliginosus	...	...	...	...	...	×	...	×	×	×	...	...	...	1 000 000	3-5	
Lupinus	*albus*	×	...	...	...	...	...	...	...	×	×	×	×	...	1 500	100-120	
	angustifolius	×	...	...	...	...	...	...	...	×	×	×	×	...	2 500	70-100	
	hirsutus	×	...	...	...	...	...	...	×	×	×	×	×	...			
	luteus	×	...	...	...	...	...	...	×	×	×	×	×	...	4 000	50-80	
	pilosus	×	...	...	...	...	...	...	×	×	×	×	×	...			
	polyphyllus	...	...	...	...	...	...	...	...	...	×	×	×	...			
Lupinus	*tassilicus*	...	...	...	...	...	...	...	...	...	×	×	×	...			
	termis	...	...	...	...	...	...	...	...	...	×	×	×	...			
Medicago	*arabica*	...	...	×	...	×	...	×	...	...	×	...	×	...	210 000	20 (hulled)	100 unhulled; 1-4 Australia
	falcata	×	...	×	...	×	...	×	...	...	×	...	×	...	230 000	10-20	
	hispida	...	...	×	...	×	...	×	...	...	×	...	×	...	140 000	20 (hulled)	1-4 Australia
	lupulina	...	...	×	...	×	...	×	...	×	×	...	×	...	300 000	10-15	
	minima	...	...	×	...	×	...	×	...	...	×	...	×	...	400 000	20 (hulled)	60 unhulled; 1-4 Australia
	orbicularis	...	...	×	...	×	...	×	...	...	×	...	×	...	150 000	20 (hulled)	1-4 Australia
	rigidula	...	...	×	...	×	...	×	...	...	×	...	×	...	150 000-200 000	20 (hulled)	1-4 Australia
	sativa	...	×	×	...	×	...	×	...	×	×	×	×	...	220 000	10-30	5-10 in rows 3-4 ft. apart
	scutellata	...	...	×	...	×	...	×	...	...	×	...	×	...	45 000	100 (unhulled)	
	truncatula	...	...	×	...	×	...	×	...	...	×	...	×	...	150 000-200 000	20 (hulled)	1-4 Australia
Melilotus	*alba*	...	×	×	...	...	...	×	...	×	×	...	×	...	260 000	10-20	
	indica	...	×	×	...	...	...	×	...	×	×	...	×	...	275 000	10-15	

Characteristics of Herbaceous and Shrubby Legumes (continued)

Genus	Species	Plant Characters									Climatic Adaptation								Soil Adaptation								Utilization					Number of Seeds per lb.	Seeding Rates lb. per acre, broadcast	Notes
		Annual	Biennial	Perennial	Erect	Prostrate	Winding, trailing	Toxic	Somewhat toxic	Drought resistant	Polar and sub-polar zones	Extended rainfall (Temperate and sub-temperate zones)	Winter rains only (Temperate and sub-temperate zones)	Summer rains only (Temperate and sub-temperate zones)	Extended rainfall (Tropical and sub-tropical zones)	Restricted rainfall (Tropical and sub-tropical zones)	Irrigation	Arid and sub-arid	Light soils	Heavy soils	Calcareous	Shallow	Well-drained	Moist	Alkaline	Acid	Green and conserved fodder	Pasture	Concentrates, human food	Green manure, soil cover	Erosion control			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
Melilotus	*officinalis*		×		×				×	×		×	×	×						×	×				×		×	×		×		260 000	10-15	unhulled 25-40
	suaveolens	×	×		×				×	×		×	×	×						×	×				×		×	×		×		250 000	10-15	
Mimosa	*invisa*	×	×	×	×	×	×								×	×														×		75 000	6-8	rows 5 ft. apart
	pudica			×	×	×									×	×												×						
Onobrychis	*viciaefolia*			×	×					×		×	×	×							×				×		×	×				25 000	30-35	
Ornithopus	*sativus*	×			×	×						×	×						×					×		×	×	×		×		160 000 (unhulled)	15-20 (unhulled)	40-60 (unhulled)
Phaseolus	*aconitifolius*	×				×				×			×	×	×	×	×										×	×	×	×		20 000	15-20 Pakistan 35-40 U. S. A.	5-6 lb. in rows 2-3 ft. apart
	acutifolius	×			×		×			×			×	×	×	×													×			25 000	25-30	
	angularis	×			×								×	×	×	×											×		×			4 000	20-25	rows 3-4 ft. apart
	aureus	×			×		×			×			×	×	×	×											×	×	×	×		10 000	60-70	
	calcaratus	×	×	×		×	×								×	×													×	×		10 000	70-80	
	lathyroides	×	×	×	×										×	×											×	×						
	lunatus			×	×		×		×						×														×	×		varying	varying	spaced (1-2) × (2-3) ft.
	multiflorus	×					×					×	×	×	×	×													×			varying	varying	
	mungo	×			×										×	×											×		×	×		varying	varying	
	radiatus	×			×	×	×			×					×	×													×				15	spaced 2x? ft., 3-7 seeds per hill
	semi-erectus	×			×					×					×	×											×		×	×				
	vulgaris	×			×							×	×	×	×	×													×			varying	varying	
Pisum	*sativum* var. *arvense*	×			×	×	×					×	×	×	×	×									×		×	×	×	×		varying	varying	
Prosopis	*glandulosa*			×	×					×			×	×	×	×		×	×			×						×	×					
Pueraria	*phaseoloides*			×		×	×			×					×	×				×				×		×	×	×		×	×	40 000	5-15 (unhulled)	3 × 3 ft. (cuttings)
	thunbergiana			×		×	×			×			×	×	×	×							×				×	×		×	×	40 000	6-10 (unhulled)	in rows 3-4 ft. apart
Rhyncosia	*minima*			×		×									×	×												×						
	phaseoloides			×		×									×	×											×		×	×				
Sesbania	*aculeata*	×			×										×	×				×				×	×					×			40-60	
	exaltata	×			×								×	×	×	×	×													×		40 000	20-25	
	macrocarpa	×			×					×			×	×	×	×	×			×				×	×					×		40 000	20	
Stizolobium	*aterrimum*	×				×				×					×	×			×	×			×				×	×	×	×				
	deeringianum	×	×	×		×	×			×			×	×	×	×			×	×			×				×	×	×	×		1 000-1 500	30-40	N. Rhodesia also spaced
	hassjoo	×	×	×		×	×			×			×	×	×	×			×	×			×				×	×	×	×		1 000-1 500	30-40	sowing 3 × 1 ft.; Queens-
	niveum	×	×	×		×	×			×			×	×	×	×			×	×			×				×	×	×	×		1 000-1 500	30-40	land 10 lb. per acre in rows 4-5 ft. apart.
Stylosanthes	*gracilis*			×	×	×				×					×	×			×	×		×	×	×		×	×	×		×			2	Queensland
	hamata			×		×				×					×	×											×	×		×				
	sundaica	×				×										×			×									×					3-4	Queensland
Swainsona	*galegifolia*			×	×				×	×			×	×		×		×										×						
	salsula			×	×				×	×			×	×		×		×										×			×			

SPECIES	Plant Characters									Climatic Adaptation								Soil Adaptation								Utilization					Number of Seeds per lb.	Seeding Rates lb. per acre, broadcast	Notes
	Annual	Biennial	Perennial	Erect	Prostrate	Winding, trailing	Toxic	Somewhat toxic	Drought resistant	Polar and sub-polar zones	Temperate and sub-temperate zones: Extended rainfall	Temperate and sub-temperate zones: Winter rains only	Temperate and sub-temperate zones: Summer rains only	Tropical and sub-tropical zones: Extended rainfall	Tropical and sub-tropical zones: Restricted rainfall	Irrigation	Arid and sub-arid	Light soils	Heavy soils	Calcareous	Shallow	Well-drained	Moist	Alkaline	Acid	Green and conserved fodder	Pasture	Concentrates, human food	Green manure, soil cover	Erosion control			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
Tephrosia candida			x	x			x							x	x								x					x	x	x	25 000	6-7	3 lb. spaced in rows 5 ft. apart
purpurea			x	x			x							x	x												x		x				
toxicaria			x	x			x							x	x														x		45 000	4-5	in rows 5 ft. apart
vogelii			x	x			x							x	x				x										x		15 000	5	in rows 5 ft. apart
Teramnus uncinatus			x			x			x					x	x												x						
Trifolium agrarium	x			x	x						x	x	x														x				1 000 000	4-8	
alexandrinum	x			x								x	x	x	x	x			x					x		x	x				200 000	40-60 (Egypt) 15-20 (U. S. A.)	20-25 lb. in Italy
arvense			x	x					x		x	x	x					x			x						x						
campestre	x			x	x						x	x	x								x				x		x				2 500 000	3-4	
carolinianum	x				x	x						x	x														x						
dubium	x			x	x						x	x	x														x				1 000 000	4-5	
fragiferum			x		x	x					x	x	x		x	x							x	x			x				300 000	5-10	
glomeratum	x				x						x	x	x														x				1 000 000	3-4	
hirtum	x			x							x	x	x												x		x				140 000	15-20	
hybridum			x	x	x			x		x	x	x	x						x				x	x	x	x	x				700 000	6-10	
incarnatum	x			x							x	x	x	x	x			x	x						x	x	x		x		140 000	15-20	
lappaceum	x			x							x	x	x													x	x				680 000	4-5	
nigrescens	x				x	x					x	x	x						x								x				1 000 000	2-4	
pannonicum			x	x							x	x														x	x						
pratense			x	x	x					x	x	x	x	x	x	x			x			x		x		x	x		x		275 000	8-12	
procumbens	x			x	x						x	x	x														x				[illegible]	3-4	
repens			x		x	x		x		x	x	x	x	x		x			x			x	x			x	x		x		[illegible]	(1); 4-6	
resupinatum	x			x								x	x	x	x	x			x				x			x	x		x		[illegible]	4-6	
striatum	x			x	x							x	x														x				[illegible]	8-12	
subterraneum	x				x	x						x			x	x								x		x	x	x	x		[illegible]	20-25 (U. S. A.)	1-5 lb. Australia
Trigonella foenum graecum	x			x								x	x	x	x	x										x			x		[illegible]	25-40 (35)	15-20 lb. non-irrigated in India
Ulex europaeus			x	x							x	x	x					x									x						
Vicia angustifolia	x			x	x						x	x	x												x	x	x		x		30 000	30-40	
articulata	x			x	x						x	x	x									x	x		x	x	x	x	x		12 000	30-80	
atropurpurea	x			x	x						x	x	x												x	x	x		x		10 000	30-40	
ervilia	x				x			x			x	x	x												x	x	x	x	x			70	
faba	x			x							x	x	x	x	x										x	x		x			varying	75-200	
grandiflora	x				x						x	x	x												x	x			x		32 000	35-40	
pannonica	x			x							x	x	x						x				x		x	x	x		x		10 000	70-80	
sativa	x			x	x	x					x	x	x	x	x							x			x	x	x	x	x		8 000	50-80	
villosa	x	x		x	x						x	x	x					x						x	x	x	x		x		17 000	30-40	
Vigna oligosperma	x	x	x		x	x			x			x	x	x	x											x	x	x	x		17 000	15-20	3 lb. in Australia;
sinensis	x			x	x	x			x			x	x	x	x	x		x	x				x	x			x	x	x		4 000	50	India; 20-30 in rows 3-4 ft. apart in the U. S. A.
Voandzeia subterranea	x		x	x	x									x	x			x						x				x				x	

Characteristics of Herbaceous and Shrubby Legumes *(concluded)*

SPECIES	Annual	Biennial	Perennial	Erect	Prostrate	Winding, trailing	Toxic	Somewhat toxic	Drought resistant	Polar and sub-polar	Extended rainfall	Winter rains only	Summer rains only	Extended rainfall	Restricted rainfall	[illegible]	[illegible]
	Plant Characters									Climatic Adaptation							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Tephrosia candida			x	x			x							x	x		
[illegible]				x			x							x	x		
[illegible]			x				x							x	x		
vogelii			x	x			x							x	x		
Teramnus uncinatus			x			x			x					x	x		
Trifolium agrarium	x			x	x						x	x	x				
alexandrinum	x			x								x	x	x	x	x	
[illegible]			x	x					x		x	x	x				
campestre	x			x	x						x	x	x				
[illegible]	x				x	x						x	x				
[illegible]	x			x	x						x		x				
[illegible]			x								x	x	x		x		
[illegible]											x		x				
[illegible]	x										x	x	x				
[illegible]			x								x	x	x				
[illegible]	x										x	x	x	x			
[illegible]	x			x							x	x	x				
[illegible]	x				x	x					x	x	x				
[illegible]			x	x							x	x					
[illegible]			x	x	x					x	x	x	x	x	x	x	
[illegible]	x			x	x						x	x	x				
[illegible]					x	x		x		x	x	x	x	x		x	
[illegible]	x			x								x	x	x	x		
striatum	x			x	x							x	x				
subterraneum	x				x	x						x			x	x	
Trigonella foenum-graecum	x			x								x	x	x	x	x	
Ulex europaeus			x	x							x	x	x				
Vicia angustifolia	x			x	x						x	x	x				
articulata	x			x	x						x	x	x				
atropurpurea	x			x	x						x	x	x				
ervilia	x				x			x			x	x	x				
faba	x			x							x	x	x	x	x		
grandiflora	x				x						x	x	x				
pannonica	x			x							x	x	x				
sativa	x			x	x	x					x	x	x	x	x		
villosa	x	x		x	x						x	x	x				
Vigna oligosperma	x	x	x		x	x			x			x	x	x	x		
sinensis	x			x	x	x			x			x	x	x		x	
Voandzeia subterranea	x		x	x	x									x	x		

SPECIES	Light soils	Heavy soils	Calcareous	Shallow	Well-drained	Moist	Alkaline	Arid	Green and conserved	Pasture	Concentrates, human	Green manure, soil	Erosion control	Seeds per lb	lb per acre broadcast	[illegible]
	Soil Adaptation								Utilization							
	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
Tephrosia candida						x					x	x	x	25 000	6-?	? lb ... in rows 5 ft apart
[illegible]										x		x				
[illegible]												x		45 000	[illegible]	[illegible]
vogelii												x		15 000	5	in rows 5 ft. apart
Teramnus uncinatus										x						
Trifolium agrarium										x				1 000 000	4-8	
alexandrinum							x		x	x		x		200 000	40-60 (Egypt) 15-20 (U.S.A.)	20-25 lb ... in Italy
[illegible]	x			x						x						
campestre				x				x		x				2 500 000	3-4	
[illegible]										x						
[illegible]										x				1 000 000	4-?	
[illegible]						x	x			x				300 000	5-10	
[illegible]										x				1 000 000	[illegible]	
[illegible]								x		x				140 000	15-?	
[illegible]						x	x	x	x	x				700 000	6-?	
[illegible]	x							x	x	x		x		140 000	?5-?	
[illegible]									x	x				680 000		
[illegible]										x				1 000 000	[illegible]	
[illegible]									x	x						
[illegible]					x		x		x	x		x		275 000	8-?	
[illegible]										x				2 000 000	[illegible]	
[illegible]					x	x			x	x		x		750 000	?-4?	
[illegible]						x			x	x		x		675 000	4-6	
striatum										x				230 000	8-12	
subterraneum							x		x	x	x	x	x	65 000	20-2? (U.S.A.)	1-5 lb ... Australia
Trigonella foenum-graecum									x			x		23 000	25-?? (35)	15-20 ... non-irrigated ...
Ulex europaeus	x									x						
Vicia angustifolia								x	x	x		x		30 000	30-40	
articulata					x	x		x	x	x	x	x		12 000	30-80	
atropurpurea								x	x	x		x		10 000	30-40	
ervilia								x	x	x	x	x			70	
faba								x	x		x			varying	75-200	
grandiflora								x	x			x		32 000	?5-40	
pannonica						x		x	x	x		x		10 000	?0-80	
sativa					x			x	x	x	x	x		8 000	?0-80	
villosa	x						x	x	x	x		x		17 000	30-?0	
Vigna oligosperma									x	x	x	x		17 000	15-20	? ft ... Australia
sinensis	x	x				x	x			x	x	x		? 000	?	India 20-30 in rows 3-4 ft. ... lb. U.S.A.
Voandzeia subterranea	x						x				x					